SHOUT
SHARE
IT

SEP 16 1985

UNIVERSITY OF
ILLINOIS LIBRARY
AT URBANA-CHAMPAIGN
GEOLOGY

Geology

FIELDIANA
Geology

Published by Field Museum of Natural History

New Series, Number 2

# ORGANIC BUILDUPS IN THE LOWER ORDOVICIAN (CANADIAN) OF TEXAS AND OKLAHOMA

DONALD FRANCIS TOOMEY
*and*
MATTHEW H. NITECKI

July 30, 1979

# ORGANIC BUILDUPS IN THE LOWER ORDOVICIAN (CANADIAN) OF TEXAS AND OKLAHOMA

FIELDIANA
Geology

Published by Field Museum of Natural History

New Series, Number 2

# ORGANIC BUILDUPS IN THE LOWER ORDOVICIAN (CANADIAN) OF TEXAS AND OKLAHOMA

DONALD FRANCIS TOOMEY
*Senior Geological Associate*
*Cities Service Company*
*Midland, Texas*
*and*
MATTHEW H. NITECKI
*Curator, Fossil Invertebrates*
*Field Museum of Natural History*
*Chicago, Illinois*

July 30, 1979

Publication 1299

*Library of Congress Catalog Card No.: 79-51552*

ISSN 0096-2651

PRINTED IN THE UNITED STATES OF AMERICA

This work is dedicated in gratitude and
respect to our friend and colleague
the late
DR. WILLIAM EUGENE HAM
1917—1970

## ABSTRACT

Organic buildups are conspicuous sedimentary features within various stratigraphic horizons of the Lower Ordovician of Texas and Oklahoma. Detailed examination and collecting of buildups exposed in the Franklin Mountains of West Texas, the Wichita Mountains of southwestern Oklahoma, and the Arbuckle Mountains of southern Oklahoma indicates that they are small-scaled features with a limited and relatively simple biotic assemblage, as are the consistently occurring accessory organisms that appear on the buildups. In some instances, a threefold vertical ecologic zonation may be apparent. The zonation seems to reflect organism response to changing physical conditions associated with progressive shallowing of the depositional environment. This sere zonation has been termed: (1) pioneer community, (2) mature community, and (3) climax community, with various organisms dominating the succession. Many organic buildups are not ecologically zoned, and this is believed to be a reflection of organisms growing and developing within a relatively unchanging shallow-water depositional environment.

Moundrock is unbedded, massive, and is characterized by *in situ* concentrations of organisms. Petrologically, moundrock can be described as burrowed, intraclastic, skeletal wackestone to boundstone. Intermound rock is darker in color, thin-bedded, and generally does not contain appreciable amounts of mound-shed debris. Erosional channels, either cutting into the mound or surrounding the organic buildups, are common in some mound intervals. The channels contain sorted calcarenites composed principally of mound-shed debris.

A feature common to all Lower Ordovician organic buildups is the almost complete absence of draping beds adjacent to the mounds. Intermound rock usually just laterally abuts into the organic buildups without significant dips.

The relative simplicity of Lower Ordovician organic buildups is to some extent explained on the basis of the rather primitive stage of development of the mound-building biota.

Coeval, faunally similar (algal/sponge) biostromal horizons in Texas are described in relationship to the buildup horizons and to their paleogeographic settings.

Comparisons of the Lower Ordovician organic buildups of West Texas and southern Oklahoma are made with reported occurrences of similar buildups in western Utah, western Canada, and western Newfoundland, and the similarities and differences noted.

Comparison is also made to temporally younger (Chazyan) organic buildups present in the Lake Champlain region of the northeastern United States. Although the Chazyan buildups are similar in gross morphology, petrology, and basic biotic composition and sequence, they do contain evolutionarily more advanced organisms possessing a greater ecologic capability to further exploit niches on organic buildups.

# TABLE OF CONTENTS


ABSTRACT ..... V

LIST OF ILLUSTRATIONS ..... IX

LIST OF TABLES ..... XIII

ACKNOWLEDGEMENTS ..... XV

INTRODUCTION ..... 1

REGISTER OF LOCALITIES ..... 3

SPONGE HORIZONS AND ORGANIC BUILDUPS IN THE LOWER ORDOVICIAN OF TEXAS ... 6

ORGANIC BUILDUPS IN THE EL PASO GROUP OF WEST TEXAS AND SOUTHERN NEW MEXICO ..... 10

- Introduction ..... 10
- Definition and Regional Relationships of the El Paso Group ..... 13
- McKelligon Canyon Formation Organic Buildups ..... 14
- Moundrock Petrology ..... 21
- Channel Rock Petrology ..... 34
- Mound Foundation ..... 35
- Intermound Rock ..... 37
- Occurrence of *Ceratopea* within the Mound Interval ..... 37
- Conodonts ..... 38
- Role of *Pulchrilamina* in West Texas Organic Buildups ..... 41
- Growth and Development of a McKelligon Canyon Formation Organic Buildup ..... 42
- Summary ..... 46

MONUMENT SPRING MEMBER OF THE MARATHON FORMATION, MARATHON REGION, SOUTHWESTERN TEXAS ..... 48

- Stratigraphic History ..... 48
- Subsequent Findings ..... 53
- Petrology ..... 53
- Megafossils ..... 53
- Conodonts ..... 55
- Summary ..... 55

ELLENBURGER SPONGE BEDS OF CENTRAL TEXAS ..... 58

- Stratigraphic Relationships ..... 58
- Lithology ..... 59
- Algal-Sponge Biostromal Units ..... 60
- Paleoecologic Setting of the Ellenburger Sponge Beds ..... 68

SPONGE HORIZONS AND ORGANIC BUILDUPS IN THE LOWER ORDOVICIAN OF OKLAHOMA ..... 72

SUMMARY OF THE GEOLOGY OF THE WICHITA MOUNTAINS ..... 76

Sections in the Wichita Mountains ..... 77
Unap Mountain Section ..... 77
Longhorn Mountain Section ..... 85
Kindblade Ranch Section ..... 95
Brief Summary of the Geology of the Arbuckle Mountains ..... 106
Sections in the Arbuckle Mountains ..... 108
Joins Ranch Section ..... 108
Highway 77 Section ..... 115
Southern Tishomingo Anticline Section ..... 126
Mill Creek Section ..... 137
Occurrence of *Ceratopea* in Oklahoma Mound Intervals ..... 143
Summary ..... 144
Value and Stratigraphic Occurrence of Certain Arbuckle Megafossils ..... 147
Comparison with Lower Ordovician Organic Buildups in Other Regions ... 151
Western Utah ..... 151
Western Canada ..... 153
Western Newfoundland ..... 154
Summary ..... 155
Comparison with Middle Ordovician (Chazyan) Organic Buildups of the Lake Champlain Region ..... 158
Summary ..... 171
References ..... 173

## LIST OF ILLUSTRATIONS


1. Occurrence of algal-sponge organic buildups and biostromal horizons in the Lower Ordovician from West Texas to southeastern Oklahoma ..... 7
2. Lower Ordovician facies belts in the southwestern United States in relationship to the outcrop areas of the Arbuckle and Wichita Mountains in southern Oklahoma, Franklin Mountains of West Texas, Marathon region of southwestern Texas and the Llano region of central Texas ..... 8
3. Lower Ordovician stratigraphy in the southern Franklin Mountains, West Texas, compared to the Ozark standard, New Mexico standard, and composite western standard ..... 11
4. Lechuguilla Mound as exposed on the scarp face of the southern Franklin Mountains, West Texas ..... 12
5. Erosional channels cut into moundrock of the El Paso Group McKelligon Canyon Formation, southern Franklin Mountains, West Texas ..... 15
6. Common skeletal components present on the surface of typical McKelligon Canyon Formation organic buildups, West Texas ..... 16
7. *Pulchrilamina* exposed on McKelligon Canyon organic buildup surfaces, West Texas ..... 18
8. Thin-section photomicrographs of McKelligon Canyon channel rock from the principal mound horizon in the southern Franklin Mountains, West Texas ..... 19
9. Lechuguilla Mound, McKelligon Canyon Formation, southern Franklin Mountains, West Texas ..... 20
10. Thin-section photomicrograph of McKelligon Canyon moundrock, southern Franklin Mountains, West Texas ..... 22
11. Outcrop photographs of small organic buildups in the McKelligon Canyon Formation, Franklin Mountains, showing climax community dominated by the laminated organism *Pulchrilamina* ..... 24
12. Thin-section photomicrographs of *Pulchrilamina spinosa* Toomey & Ham from principal McKelligon Canyon mound horizon in southern Franklin Mountains, West Texas ..... 26
13. Thin-section photomicrographs of *Pulchrilamina spinosa* Toomey & Ham showing irregular distribution of spines and entrapped mud on laminae, southern Franklin Mountains, West Texas ..... 27
14. Thin-section photomicrographs of various sponge spicules found in McKelligon Canyon moundrock, southern Franklin Mountains, West Texas ..... 28
15. Photomicrographs of various organisms occurring in typical McKelligon Canyon moundrock, southern Franklin Mountains, West Texas ..... 29
16. Silicified brachiopods *(Finkelnburgia)* from McKelligon Canyon moundrock, southern Franklin Mountains, West Texas ..... 30

17. Silicified brachiopods *(Oligorthis)* from McKelligon Canyon moundrock, southern Franklin Mountains, West Texas ..... 31
18. Thin-section photomicrographs showing algal? boring effects on various grains, McKelligon Canyon Formation, southern Franklin Mountains, West Texas ..... 32
19. Field sketch showing small scale digitate stromatolite colonies encrusting mound foundation and tumbled sponge fragments, McKelligon Canyon moundrock, southern Franklin Mountains, West Texas ..... 33
20. Silicified fossils from the McKelligon Canyon Formation, southern Franklin Mountains, West Texas ..... 36
21. Schematic diagram showing mound occurrences and position of thin *Ceratopea* zone present in the McKelligon Canyon Formation, southern Franklin Mountains, West Texas ..... 39
22. Diagramatic sequence of growth stages and burial of McKelligon Canyon Formation organic buildup ..... 45
23. Thin-section photomicrographs of typical Monument Spring Member lithologies ..... 52
24. Representative Lower Ordovician conodonts found in the organic buildups and sponge horizons of Texas and Oklahoma ..... 54
25. Stratigraphic distribution of sponge horizons in the middle and upper Ellenburger Group of central Texas ..... 59
26. Thin-section photomicrographs of typical Ellenburger sponge-bearing rock of central Texas ..... 62
27. Photographs of the main sponge-bearing horizon present in the Ellenburger Honeycut section at Rough Hollow, central Texas ..... 65
28. Typical silicified *Archaeoscyphia* along with representative lithistid sponge spicules retrieved from acid etching, Honeycut Formation, central Texas ..... 69
29. Schematic diagram of an algal-sponge-bearing biostromal unit in the Honeycut Formation of central Texas ..... 70
30. Location map showing Lower Ordovician Kindblade sections in the Wichita and Arbuckle Mountains of southern Oklahoma ..... 73
31. Stratigraphic and geographic distribution of *Archaeoscyphia* and *Calathium* in lower part of Kindblade Formation, Wichita and Arbuckle Mountains, southern Oklahoma ..... 74
32. Algal-sponge mounds in zone of abundant *Calathium* at the Unap Mountain section in the Wichita Mountains ..... 78
33. Close-up photographs of various digitate algal stromatolite colonies adjacent to organic buildups on Unap Mountain, Wichita Mountains, southwestern Oklahoma ..... 79
34. Outcrop photographs of the Unap Mountain section and a chertified colony of *Pulchrilamina* from the Roosevelt Material Company quarry .... 80
35. Thin-section photomicrograph of typical moundrock from zone of abundant *Calathium* on Unap Mountain in the Wichita Mountains ..... 82
36. Thin-section photomicrograph of moundrock boundstone from zone of abundant *Calathium* on Unap Mountain in the Wichita Mountains ..... 83
37. Overlay of a polished slab of moundrock from upper mound horizon, Unap Mountain section, Wichita Mountains ..... 84
38. Thin-section photomicrograph of lithologies of the upper mound horizon substrate at Unap Mountain, Wichita Mountains ..... 87

39. Outcrop photographs of the Longhorn Mountain section in the Wichita Mountains ..... 88
40. Small algal mound structures (miniherms) occurring on Kindblade bedding plane surfaces in lower mound interval on Longhorn Mountain, Wichita Mountains ..... 89
41. Close-up photographs of silicified fossils on mound surfaces in zone of abundant *Calathium* at the Longhorn Mountain section, Wichita Mountains ..... 90
42. Overlay of a polished slab of moundrock from zone of abundant *Calathium* at Longhorn Mountain, Wichita Mountains ..... 91
43. Schematic diagram of large Kindblade mound complex in upper mound horizon at Longhorn Mountain, Wichita Mountains ..... 92
44. Thin-section photomicrographs of off-mound lithologies present in upper mound interval at Longhorn Mountain, Wichita Mountains ..... 93
45. Outcrop photographs of the Kindblade Ranch section, Wichita Mountains, southwestern Oklahoma ..... 94
46. Outcrop photographs of mound surfaces showing abundant sponges, Kindblade Ranch section, Wichita Mountains ..... 96
47. Outcrop photograph showing lateral relationships between mound and intermound rocks in the lower mound horizon at the Kindblade Ranch section in the Wichita Mountains ..... 98
48. Diagram of organic buildup complex in zone of abundant *Archaeoscyphia* at the Kindblade Ranch section in the Wichita Mountains ..... 99
49. Close-up photographs of algal "miniherms" in the lower mound interval at the Kindblade Ranch section in the Wichita Mountains ..... 100
50. Thin-section photomicrographs of typical moundrock from organic buildup interval in zone of abundant *Archaeoscyphia*, Kindblade Ranch section, Wichita Mountains ..... 101
51. Thin-section photomicrograph of moundrock from upper mound interval (zone of abundant *Calathium*), Kindblade Ranch section, Wichita Mountains ..... 104
52. Schematic diagram of a typical lower Kindblade mound horizon as seen at the Joins Ranch section, Arbuckle Mountains, southern Oklahoma ..... 109
53. Outcrop photographs of organisms present on organic buildups from the lower and upper mound intervals at the Joins Ranch section, Arbuckle Mountains, southern Oklahoma ..... 110
54. Thin-section photomicrographs of typical Kindblade moundrock from zone of abundant *Calathium* at the Joins Ranch section, Arbuckle Mountains, southern Oklahoma ..... 112
55. Thin-section photomicrographs of calcified *Archaeoscyphia* from an interval 350 ft. above the base of the Kindblade Formation at the Joins Ranch section, Arbuckle Mountains, southern Oklahoma ..... 113
56. Outcrop photograph of Kindblade sequence at the Highway 77 section showing its typical outcrop expression, and thin-section photomicrograph of skeletal wackestone from lower mound interval at the Highway 77 section, Arbuckle Mountains ..... 114
57. Schematic diagram of algal-sponge mounds in lower mound interval of Kindblade Formation at the Highway 77 section, Arbuckle mountains, southern Oklahoma ..... 115
58. Domal algal stromatolite colonies developed on bedding plane surfaces of

lower mound intervals (zone of abundant *Archaeoscyphia*) at the Highway 77 section, Arbuckle Mountains ..... 116
59. Thin-section photomicrograph of stromatolitic boundstone from lower mound interval at the Highway 77 section, Arbuckle Mountains ..... 117
60. Outcrop photographs of surface of a typical lower mound horizon showing principal organic components as exposed at the Highway 77 section, Arbuckle Mountains ..... 118
61. Thin-section photomicrographs of typical moundrock from lower mound interval (zone of abundant *Archaeoscyphia*) at the Highway 77 section, Arbuckle Mountains, southern Oklahoma ..... 120
62. Thin-section photomicrograph of a stromatolite colony present in the upper mound interval (zone of abundant *Calathium*) at the Highway 77 section, Arbuckle Mountains ..... 122
63. Thin-section photomicrograph of algal boundstone from upper mound interval at the Highway 77 section, Arbuckle Mountains ..... 123
64. Thin-section photomicrographs of various lithologies present in the upper mound interval at the Highway 77 section, Arbuckle Mountains ..... 124
65. Thin-section photomicrographs of various organisms seen in the lower mound interval at the Southern Tishomingo Anticline section, Arbuckle Mountains, southern Oklahoma ..... 127
66. Thin-section photomicrograph of moundrock from the lower mound interval (zone of abundant *Archaeoscyphia*) at the Southern Tishomingo Anticline section, Arbuckle Mountains ..... 128
67. Thin-section photomicrograph of moundrock from upper mound interval (zone of abundant *Calathium*) at the Southern Tishomingo Anticline section, Arbuckle Mountains, southern Oklahoma ..... 129
68. Outcrop photograph and thin-section photomicrograph of small "pseudomounds" abundantly exposed on a bedding plane surface 25 ft. above the base of the Kindblade Formation at the Mill Creek section, Arbuckle Mountains, southern Oklahoma ..... 130
69. Outcrop photographs of sponges and receptaculitid algae from the lower mound interval (zone of abundant *Archaeoscyphia*) at the Mill Creek section, Arbuckle Mountains ..... 132
70. Outcrop photographs of mound surfaces showing organism burrows and algal heads from the lower mound interval at the Mill Creek section, Arbuckle Mountains, southern Oklahoma ..... 133
71. Outcrop photographs showing intermound rock and a mound surface in the upper mound interval at the Mill Creek section, Arbuckle Mountains ..... 134
72. Schematic diagram of an organic buildup in the zone of abundant *Calathium* exposed at the Mill Creek section, Arbuckle Mountains, southern Oklahoma ..... 135
73. Outcrop photographs of small algal mounds "miniherms" occurring on a bedding plane surface 450 ft. above the base of the Kindblade Formation at the Mill Creek section, Arbuckle Mountains ..... 136
74. Overlay of a polished slab of moundrock from the upper mound interval at the Mill Creek section, Arbuckle Mountains, southern Oklahoma ..... 137
75. Thin-section photomicrograph of typical moundrock from the zone of abundant *Calathium* at the Mill Creek section, Arbuckle Mountains ..... 138

76. Thin-section photomicrographs of the problematical organism *Pulchrilamina* from an organic buildup in the upper mound interval at the Mill Creek section, Arbuckle Mountains, southern Oklahoma ..... 140
77. Stratigraphic range chart of most common fossils occurring in the lower Kindblade and upper Cool Creek Formations in Wichita and Arbuckle Mountains, southern Oklahoma ..... 148
78. Thin-section photomicrographs showing mound and intermound lithologies of lowermost Day Point (Chazyan) organic buildups exposed on Garden Island in Lake Champlain, New York ..... 160
79. Thin-section photomicrograph showing upper Day Point moundrock dominated by encrusting sheets of trepostome bryozoans, exposed on Isle La Motte, western Vermont ..... 162
80. Outcrop photographs of bryozoan organic buildups exposed in the upper Day Formation on Isle La Motte, western Vermont ..... 163
81. Outcrop photographs of Crown Point organic buildups, and algal oncolites on mound surfaces exposed on Isle La Motte, western Vermont ..... 164
82. Outcrop photograph of a typical Crown Point organic buildup as exposed in a pasture on Isle La Motte, western Vermont ..... 165
83. Recrystallized remains of the red alga *Solenopora*? from a Crown Point mound surface exposed on Isle La Motte, western Vermont ..... 167
84. Lithistid sponges present in the Crown Point Formation of the Lake Champlain area of northeastern New York and western Vermont ..... 168
85. Outcrop photograph of a channel cutting moundrock in Crown Point Formation exposed on Isle La Motte, western Vermont ..... 170

## LIST OF TABLES

1. Conodont assemblages from McKelligon Canyon mound horizons, southern Franklin Mountains, West Texas ..... 40
2. Conodont assemblages from several exotic blocks of the Monument Spring Member of the Marathon Formation, southwest Texas ..... 56
3. Conodont assemblages from the Kindblade mound horizons and Honeycut horizons of abundant sponges in southern Oklahoma and central Texas ... 66
4. Conodont assemblages from the Kindblade mound horizons of abundant *Calathium* in southern Oklahoma ..... 102

## ACKNOWLEDGEMENTS

Many individuals have contributed time, talent, and encouragement during the lengthy time it has taken to complete this study. Foremost is the late Dr. William E. Ham of the Oklahoma Geological Survey who helped initiate and guide the early and formative stages of this study, and gave most willingly of his extensive knowledge of the geology of Oklahoma; for this we are deeply appreciative. Accordingly, this study is dedicated to his memory.

Thanks are due to Dr. James Lee Wilson of Rice University who initially suggested an overall and more comprehensive study of the Lower Ordovician organic buildups of the southwest.

Special appreciation is due to Dr. Raymond L. Ethington of the University of Missouri for identification of conodonts listed in Tables 1-4; for the stratigraphic data; for providing us with Figure 24; and, finally, for the information on Lower Ordovician correlation.

The following colleagues spent time in the field and helped with various aspects of field work and with the identification of fossils: Drs. Virgil Barnes, James Derby, Robert M. Finks, Philip Heckel, David LeMone, Otto P. Majewske, Max Pitcher, Richard Rezak, George A. Sanderson, and James Lee Wilson.

Dr. Barnes loaned selected Ellenburger fossils for study and Dr. LeMone helped with statistical analysis. Don Parker, Phil O'Neil, Bob Girndt, David Fogt, and Alex Kilby assisted in the field and laboratory. Alisanne Toomey and Carole Schumacher prepared the illustrations.

We wish to acknowledge with thanks the following colleagues who have given extensively of their expertise and aided in identifying much of the collected fossil material: the late Dr. J. Harlan Johnson (algae and *problematica*), Dr. John L. Wray of the Marathon Oil Company Research Laboratory (algae and *problematica*), Dr. J. Keith Rigby of Brigham Young University (sponges), Dr. Joseph St. Jean of the University of North Carolina

(stromatoporoids), Dr. June Ross of Western Washington State University (bryozoans), Dr. G. Arthur Cooper of the U.S. National Museum (brachiopods), Dr. Ellis Yochelson of the U.S. Geological Survey (gastropods), Dr. A. G. Unklesday of the University of Missouri (cephalopods), Dr. Reuben Ross of the U.S. Geological Survey (trilobites), and Dr. Gilbert Klapper of the University of Iowa (conodonts).

Through the courtesy of Shell Development Company, Houston, Texas, Toomey spent four weeks during the summers of 1962 and 1963 collecting and examining the organic buildups in and around the Lake Champlain area of western Vermont and eastern New York. We are grateful to Dr. Frank Wantland, Director of Research at the Cities Service Oil Company research facility in Tulsa, for financial aid to Toomey to complete the field studies. Field Museum of Natural History supported the junior author's two field trips to El Paso and one to Arbuckle Mountain in the summers of 1967, 1968, and 1970. Finally, we acknowledge the financial support of the National Science Foundation grant DEB 77-11129 to the junior author.

## INTRODUCTION

The present study is primarily concerned with a systematic description of Lower Ordovician sponge horizons and algal-sponge organic buildups found in the Texas-Oklahoma region; it is not however, concerned with the systematic paleontology. The revision of *Calathium*, and related forms now in progress, will follow and supplement the present research.

The stratigraphic interval that this report considers is that portion of the upper Lower Ordovician referred to the El Paso Group (McKelligon Canyon Formation) of West Texas, Marathon Formation (Monument Spring Dolomite Member) of southwest Texas, Ellenburger Group (Honeycut Formation) of central Texas, and the lower 500 ft. of the Arbuckle Group (Kindblade Formation) of southern and southwestern Oklahoma.

The two outstanding recent studies of organic buildups are Ross' (1972) examination of the giant Antelope Valley limestone bioherm in Nevada and Alberstadt & Walker's (1975) description of Elk River "Reef" of Tennessee. However, these are stratigraphically and geographically outside of our area of research, and, although they may contain similar fossil elements, they are significantly different from our structures and are not compared to our organic buildups.

Extensive field work and fossil collecting over the past decade has given us a firmer basis for regional stratigraphic correlations. This information has been co-ordinated with detailed petrographic analyses, thus allowing more precise interpretations of the regional paleoenvironmental setting during this period of geologic time.

Organic buildups, dominantly of algal-sponge composition, occur in some of the studied stratigraphic horizons present in both the El Paso and Arbuckle rock sequences. Much work has been devoted to detailed study of these early organic structures, and especial effort has been made to tie-in and relate the petrology and mound biotas. New fossil elements *(problematica*, algae, sponges, chitons,

cephalopods, and conodonts) have been found during this study, and these finds have added materially to our overall understanding of Lower Ordovician biotas, especially mound biotas.

In the Oklahoma sequence, earlier determined fossil data has been combined with that obtained during this study and a chart delineating the stratigraphic ranges of significant fossils has been included.

Representative specimens consisting of fossils, rock specimens, polished rock slabs, thin-sections, and pertinent photomicrographs have been deposited with and incorporated into the collections of Field Museum of Natural History.

## REGISTER OF LOCALITIES

**Southern Franklin Mountains, West Texas.**

The McKelligon Canyon Formation was studied at the Cloud & Barnes (1948) El Paso measured section shown on their figures 5 and 6, and fully described on their pages 361-369. Detailed field work demonstrated that better exposed horizons of interval 15, containing abundant organic buildups, were located approximately one-quarter mile south of the Cloud & Barnes section. Accordingly, most of the pertinent field data and collections were obtained from this area. LeMone (1969a, p. 151) later redefined the type section of the McKelligon Formation from this same area and noted that "the base of the McKelligon Canyon Formation type section is 1 mile west and 1500 feet south of the intersection of longitude 106°27'30" and latitude 31°47'30" (El Paso, Texas, 7.5 minute quadrangle, 1955), El Paso County Texas. This section is easily reached, and is located approximately 0.1 mile southwest of a quarry used as a pistol range by the El Paso Police Academy (shown as a quarry on the Cloud & Barnes map, 1948, fig. 5), and right off the Scenic Drive road. The thickness of the McKelligon Canyon Formation type section is approximately 675 ft.

**Marathon Uplift, Southwest Texas.**

Two sections of the entire Marathon Formation, as exposed in the Marathon Anticlinorium, were measured and samples collected in 1955.

1. Section measured along Alsate Creek, approximately 3 miles west-southwest of old Fort Pena Colorado, Brewster County, southwestern Texas. Total thickness of section is approximately 515 ft.; thickness of the Monument Spring Member (chaotic boulder bed) is about 70 ft.

2. Section measured 2½ miles southwest of Alsate Creek, and ½ mile southeast of the main ranch road, Brewster County, southwest Texas. Total thickness of the Marathon Formation is approximately 680 ft.; thickness of the Monument Spring Member (chaotic boulder bed) is 55 ft.

**Llano Region, Central Texas.**

Samples from two sponge-bearing beds present in the lower Honeycut Formation, Honeycut Bend, Blanco County, central Texas, were collected in 1960. Both of these units are accurately delineated on the geologic map given on Plate 3 of Cloud & Barnes (1948).

1. Rough Hollow locality exposed in the Honeycut Bend area, Blanco County, central Texas. This is Cloud & Barnes' (1948, p. 327) unit 100 of Section 8E, the Rough Hollow section. The sponge-bearing bed is 5 ft. thick and crops out 3½ miles east of the courthouse at Johnson City, and is the first sponge bed mapped east of Rough Hollow.

2. The Burke Ranch locality is located 6 miles northeast of the Blanco County courthouse at Johnson City, and 1 mile south of the Cypress Mill Road near the northernmost pipeline, which is north of the Shell pipeline on the Burke Ranch. This unit is 4 ft. thick.

**Arbuckle Mountains, Southeastern Oklahoma.**

1. Joins Ranch section: located on the original Joins Ranch, SE¼ NW¼ sec. 4, T. 2 S., R. 1 W., Murray County, Oklahoma, approximately 6 miles north of Woodford, Strata dip 30 deg. southwestward and are well exposed, but are accessible only by primitive road.

2. Highway 77 section: located in limestone outcrops dipping 60 deg. homoclinally southwestward on both sides of U.S. Highway 77, S½ NW¼ sec. 19, T. 2 S., R. 2 E., Carter County, Oklahoma. The mound horizons cross Highway 77 at a point approximately one-half to three-quarters of a mile south of the Murray-Carter County line, on the south flank of the Arbuckle Anticline.

3. Southern Tishomingo Anticline section: located at the Center NW¼ NE ¼ sec. 8, T. 3 S., R. 4 E., Johnson County, Oklahoma.

4. Mill Creek section: located 6 miles west-southwest of Mill Creek village, SW¼ SW¼ SE¼ sec. 17, T. 2 S., R. 4 E., Murray County, Oklahoma. Beds dip 12 deg. homoclinally westward, in the northern part of the Tishomingo Anticline.

**Wichita Mountains, Southwestern Oklahoma.**

1. Unap Mountain section: located in the Roosevelt Materials Company Quarry at Unap Mountain, SW¼ SE¼ SW¼ sec. 32, T. 6 N., R. 15 W., Kiowa County, Oklahoma.

2. Kindblade Ranch section: located 10½ miles south of the town of Carnegie on the Kindblade Ranch. The strata dip 25 deg.

northeast with exposures in the scarp face at SW ¼ NE ¼ and SE ¼ NW ¼ sec. 25, T. 6 N., R. 14 W., Kiowa County, Oklahoma.

3. Longhorn Mountain section: located near the top of Longhorn Mountain at SE ¼ SE ¼ SW ¼ sec. 2, T. 5 N., R. 15 W., Kiowa County Oklahoma.

## SPONGE HORIZONS AND ORGANIC BUILDUPS IN THE LOWER ORDOVICIAN OF TEXAS

The classic monograph by Cloud & Barnes (1948) on the Ellenburger Group of central Texas focused attention on this unique sequence of Lower Ordovician rocks exposed in the state. Not only were the Ellenburger rocks of the Llano region of central Texas studied and mapped in detail, but other Lower Ordovician sections exposed elsewhere in the state, namely the Marathon Limestone of southwestern Texas and the El Paso Group of far West Texas, were studied, samples collected, and their stratigraphic and faunal relationships to the Ellenburger Group defined.

The Cloud & Barnes report is important because it marks what can be regarded as the Renaissance in carbonate studies. This report was one of the first works to bring into play much of the early knowledge that had been gathered by the late 1930's and early 1940's relating to an increasing awareness of the importance of carbonate studies, especially as viewed from a paleoecological standpoint. The usefulness of Recent depositional models, in this instance the use of the Bahama Bank model, was fully recognized and utilized in attempting to make meaningful paleoecological interpretations in relationship to Texas Lower Ordovician depositional environments. In essence, the Ellenburger report set the standard for later carbonate workers to follow, and the full blossoming of the Recent model-ancient analog approach owes much to this 30-year-old monograph.

Sponge horizons and organic buildups that are composed chiefly of algae and sponges are common in some stratigraphic intervals of the Lower Ordovician of Texas. These are shown in Figure 1 and their relationships to coeval horizons in Oklahoma are included.

Figure 2 is a generalized diagram of the two principal Lower Ordovician facies belts present in the area from Oklahoma to far West Texas during this time. Trending diagonally across the diagram is a sinuous line marking the approximate northwestern edge of the

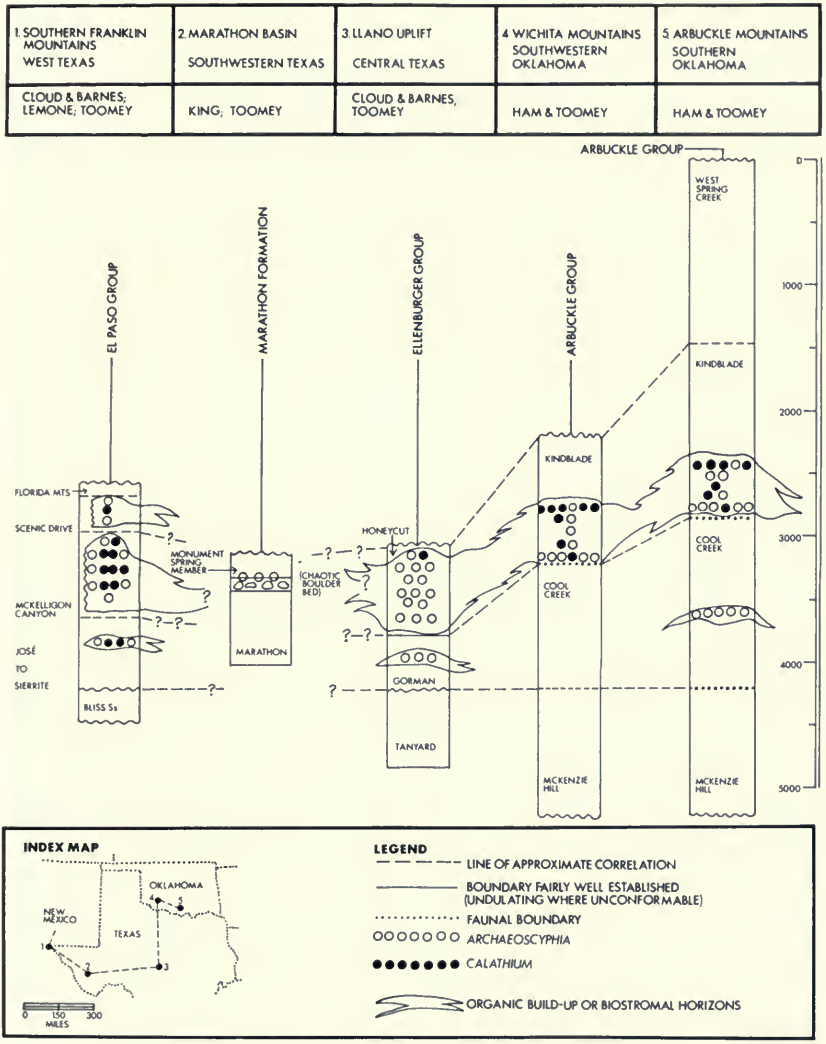



FIG. 1. Occurrence of algal-sponge organic buildups and biostromal horizons in the Lower Ordovician from West Texas to southeastern Oklahoma (modified from Toomey, 1964).

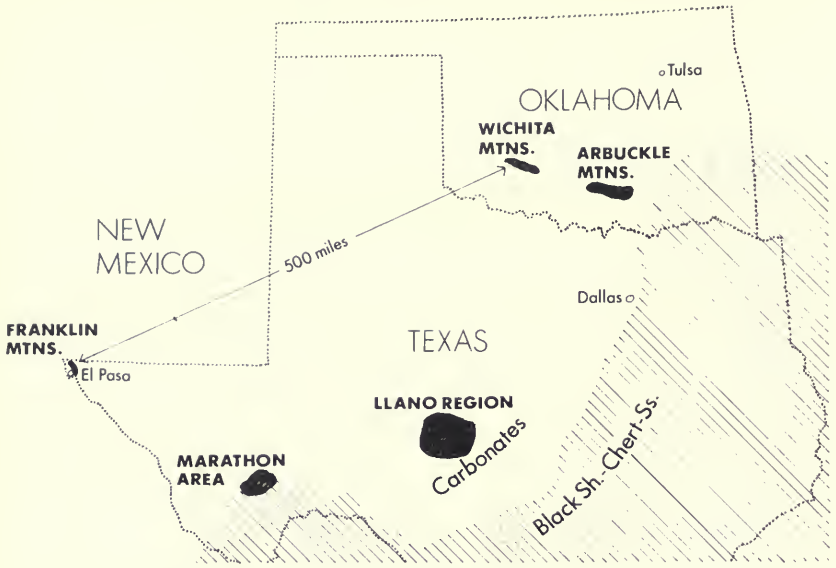



FIG. 2. Generalized diagram of Lower Ordovician facies belts in the southwestern United States in relationship to the outcrop areas of the Arbuckle and Wichita Mountains in southern Oklahoma, Franklin Mountains of West Texas, Marathon region of southwestern Texas and the Llano region of central Texas.

Quachita facies which consists mostly of black shale and sandstone, together with a little chert. To the northwest is a broad belt of carbonate rocks, at least 500 miles wide and extending some 2,000 miles northeastward up into Newfoundland. These carbonates were deposited in the shallow waters of a broad and elongate platform marking the edge of the craton. Upon this carbonate platform, shallow water plants and animals thrived and developed distinct biotic communities. During Lower Ordovician time, specifically early Kindblade-Honeycut-McKelligon Canyon-Monument Spring time, the lithistid sponge *Archaeoscyphia*, the alga *Calathium* (see below), and the probable coelenterate *Pulchrilamina* began to flourish and, acting together, locally built either biostromal horizons or low, mounded organic buildups in the shallow seas. Organic buildups of this composition are abundant during this time interval in parts of the Wichita Mountains and the Arbuckle Mountains of southern Oklahoma, the Franklin Mountains at El Paso, in far West Texas, and in some of the mountain ranges in southern New Mexico. Airline distance between the Oklahoma and Texas areas of abundant organic buildups is approximately 500 miles. The known area of organic buildups lies wholly within the carbonate

platform 50 to 100 miles northwestward of the boundary delineating the Quachita facies clastic belt. For convenience, the Texas sections beginning with the El Paso Group of far West Texas, will be discussed first; followed by a discussion and description of the southern Oklahoma localities.

## ORGANIC BUILDUPS IN THE EL PASO GROUP OF WEST TEXAS AND SOUTHERN NEW MEXICO

**Introduction**—Relatively small-scaled organic buildups are a conspicuous sedimentary feature within a number of stratigraphic horizons of the Lower Ordovician El Paso Group, in far West Texas and southern New Mexico. The best-developed, abundant, and well-exposed organic buildups are in the early upper Canadian strata of the southern Franklin Mountains of West Texas, in what Cloud & Barnes (1948) designated as interval 15 of subunit $B_1$. More recently, Flower (1964) and LeMone (1969a) have redefined the entire El Paso Group of this region and subdivided this 1,590 ft. rock sequence into a number of new members and formations (fig. 3). Accordingly, the organic buildups discussed in this section are now placed in the lower portion of the McKelligon Canyon Formation.

The size of the organic buildups varies markedly. For the most part they are rather small sedimentary features from 3-5 ft. in length and up to 6 ft. in height. Lechuguilla Mound, the largest organic buildup encountered in the El Paso Group, is approximately 45 ft. long and 19 ft. high (fig. 4). Many of the larger mounds contain conspicuous channels filled with coarse calcarenitic debris; this channel-fill is sometimes cross-bedded (fig. 5). The McKelligon Canyon organic buildups are massive non-bedded muddy carbonates containing a distinctive biota, and enclosed and surrounded by thinner, well-bedded carbonate units containing much clastic debris.

Organic buildups in the El Paso Group, specifically in the southern Franklin Mountains of far West Texas, are not restricted only to those rocks placed within the McKelligon Canyon Forma-

---

*Opposite:*

FIG. 3. Lower Ordovician stratigraphy in the southern Franklin Mountains, West Texas, compared to the Ozark standard, New Mexico standard, and the composite western standard.

| LOWER ORDOVICIAN (CANADIAN) | | Ozark Standard G.S.A. (1954) | New Mexico-West Texas Standard Flower (1957) | New Mexico-West Texas Divisions Flower (1964) | New Mexico West Texas Chronozones Flower (1964) | Composite Garden City-Iben Area, Utah Western U.S. Standard Hintze (1951, 1952); Ross (1951) | | European Standard |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Zone | Fauna | |
| LATE UPPER | | Smithville-Black Rock | Cassinian | Florida Mountains | Buttsoceras | K (?)<br>J | Hesperonomella minor<br>Pseudocyclele nasuta | ARENIG |
| | | Powell Cotter | | Scenic Drive | Cassinoceras | I | Paranileus ibexensis | |
| | | | | | Ceratopea buttsharmi | H (?) | Trigonocerca typica | |
| EARLY UPPER | | No Apparent Equivalent | Jeffersonian | McKelligon Canyon | Ceratopea ankylosa | | | |
| | | | | | Fourth Piloceroid | G-2 | Protopliomerops contracta | |
| | | Jefferson City | | | Third Piloceroid | | | |
| | | | | | Second Piloceroid | G-1 | Protopliomerops ceisaore | |
| | | | | | McQueenoceras | | | |
| MIDDLE | | No Apparent Equivalent | Deminguian | Snake Hills | Leiostegium-Paramleves | F | P. superciliosa | |
| | | | | Mud Springs Mountain | Bridgeites | F | P. superciliosa | |
| | | Roubidoux | | José | Bridgeina-Aulacoparia | E (?) | Tesselacauda | |
| | | | | Victorio Hills | Bisonoceras | E | Tesselacauda | |
| | | | | Cooks | First Endoceroid | D-2 | Leiostegium-Kaimella | TREMADOC |
| | | No Apparent Equivalent | | Big Hatchet | Leiostegium-Kaimella | D-1 | Leiostegium-Kaimella | |
| LOWER | | Gasconade | Gasconadian | Siernite (restricted) | Lytospira-Symphysurina brevispicata | C (?)<br>B | Parapeltopeltis Symphysurina | |
| | | Van Buren | | Bliss | Apheoorthis mentia | A | Nanoths-Bellefontia | |

| S. Franklin Mountains | | | | Central Texas Cloud and Barnes (1948) |
|---|---|---|---|---|
| LeMone (1969) | C & B (1948) | | | |
| | Interval | Unit | | |
| Florida Mountains Formation | 1-8 | C | EL PASO GROUP | ELLENBURGER GROUP |
| Scenic Drive Formation: Nameless Canyon Member | 7-10 | $B_2b$ | | Eroded |
| Scenic Drive Formation: Black Bench Member | | | | |
| McKelligon Canyon Formation | 11-14 | $B_2a$ | | |
| | 15 | $B_1$ | | Honeycut |
| Platot Range Member | 16 & upper 17 | | | |
| | Missing | | | |
| José Formation | lower 17 and 18 | | | |
| Victoria Hills Formation | 19-22 | A | | Gorman |
| Cooks Formation | 23-24 | | | |
| | Missing (?) | | | |
| Siernite Formation (restricted) | 25-27 | A | | Tanyard |
| Bliss Sandstone | Bliss | | | |

tion, but occur in rocks both older and younger. The organic buildups of the McKelligon Canyon Formation are, however, much more numerous, better exposed, more accessible, and contain a more easily collectable biota than those of the other mound-bearing horizons. The organic buildups are more common in the lower 200 ft. of the formation in the sequence Cloud & Barnes assigned to interval 15, subunit $B_1$ (fig. 3).

**Definition and Regional Relationships of the El Paso Group**—George B. Richardson (1904, p. 29), the early Texas railroad geologist, named the Ordovician rocks exposed in the Franklin Mountains of West Texas as the El Paso Limestone. Later, Richardson (1908, pp. 467-479) restricted the name El Paso Limestone to rocks of Lower Ordovician age, and described it as a "gray, chiefly magnesian limestone, usually massive, but locally thin-bedded." Cloud & Barnes (1948, pp. 61-72) elevated the El Paso Limestone to formational rank, and described it as "1590 feet of limestone, dolomite, a little shale and less sands." Kelley & Silver (1952, pp. 42-49) further raised the El Paso Formation to group status. Flower (1964, pp. 148-149), on extensive study of the cephalopod faunas, subdivided the entire El Paso Group into faunal zones, and named several new formations and members. Unfortunately, definitive data on formation type localities was lacking. Finally, in 1969a, LeMone (pp. 18-22) supplied the necessary type locality data and formalized some of the previously named units.

In New Mexico, outcropping Lower and Middle Paleozoic (Cambrian-Devonion) strata are confined chiefly to the southern portion of the state. As such, the Lower Ordovician El Paso Group strata wedge out in a northward direction, and the northernmost limit of these strata occurs at the northern end of the Fra Cristobal Mountains, in Sierra County. This northward wedging-out of rock units is a result of erosional truncation accompanied by southward structural tilting of the region during post-Devonian time. This is best shown in sections from the Franklin Mountains, north of the Organ Mountains, and across the lengthy San Andres range. Kottlowski (1963, p. 16) emphasized Cloud & Barnes' thickness of

---

*Opposite:*

FIG. 4. Lechuguilla Mound as exposed in the lower part of the McKelligon Canyon Formation, southern Franklin Mountains at El Paso, West Texas. This organic buildup is approximately 19 ft. high and 45 ft. wide, and is cut by dark-colored calcarenite-filled channels.

1,590 ft. of El Paso sediments at the southern end of the Franklin Mountains, but in the southern San Andres Mountains, near Ash Canyon, the El Paso sediments have thinned to 760 ft. At Hembrillo Canyon the El Paso is 535 ft. thick, whereas to the north at Rhodes Canyon and Sheep Mountain, thicknesses are 305 and 285 ft., respectively. At the northern end of the range, at Mockingbird Gap, the El Paso interval is only 40 ft. thick.

The El Paso Group as developed in southern New Mexico, and far West Texas, is continuous with, and a facies expression of, the Ellenburger Group of the outcrop area in central Texas and the subsurface of West Texas. In southwestern New Mexico, the El Paso Group is probably correlative with a portion of the Abrigo Limestone of Arizona. The El Paso Group undoubtedly represents a sedimentary sequence that is generally time-transgressive from west to east. Recent work by Hayes (1975) demonstrates that the Cambro-Ordovician sedimentary patterns seen in this region are illustrative of a series of complex transgressions and regressions, rather than a simple, single transgression.

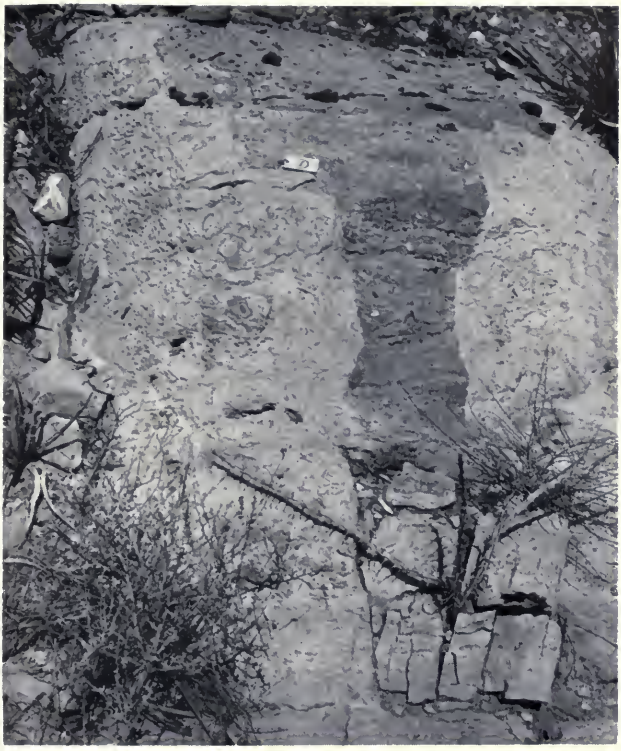
**McKelligon Canyon Formation Organic Buildups**—Cloud & Barnes (1948, p. 365) were the first to recognize mound structures in the El Paso sediments. They lucidly described the mound-bearing sequence at the southern end of the Franklin Mountains with the statement that "considerable stromatolitic structure is locally evident in the more massive limestone units of interval 15 and *Calathium* and piloceratid siphuncles are commonly abundant in such beds." Ham & Toomey (1966, pp. 83-84) recognized the "stromatolitic structures" as organic buildups *per se* and noted that the primary mound contributor was not stromatolites, but a previously unknown colonial organism of possible coelenterate affinity which they discussed in detail and formally described as *Pulchrilamina spinosa* (Toomey & Ham, 1967).

Kelley & Silver (1952, pp. 46-50), in their study of the El Paso sediments of the Caballo Mountains of south-central New Mexico,

---

*Opposite:*

FIG. 5. Outcrop photographs showing channels that have cut through the lighter-colored moundrock in the principal mound horizon of the McKelligon Canyon Formation, southern Franklin Mountains, West Texas. (a) This channel is approximately 3 ft. wide at the top of the mound, but narrows to approximately 1 ft. in width near the base of this particular organic buildup. (b) Channel-filling calcarenites (marked-C) on Lechuguilla Mound. The channel-filling is slightly cross-bedded and consists of shell debris and intraclasts.



a

b

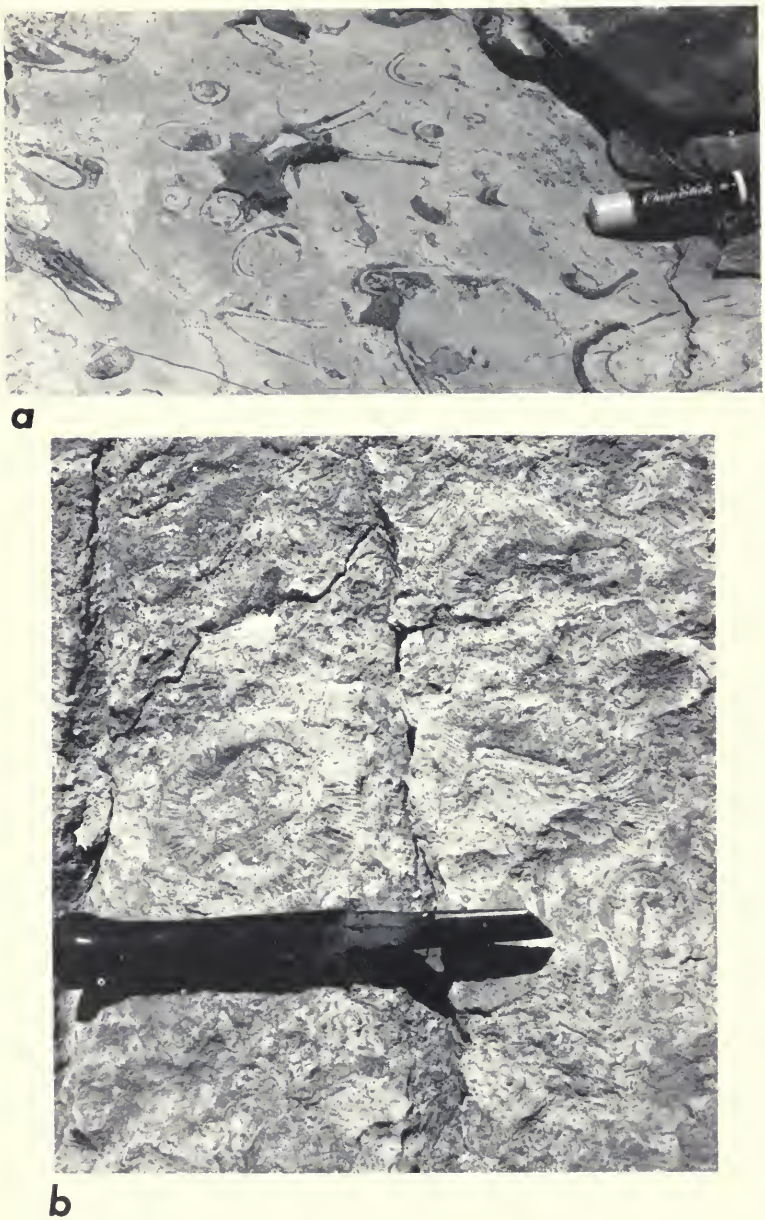



FIG. 6. Outcrop photographs of characteristic fossils exposed on the mound surface within the principal organic buildup horizon in the McKelligon Canyon Formation, southern Franklin Mountains, West Texas. **(a)** Abundant silicified specimens of the receptaculitid alga *Calathium;* note root system on large specimen in center of photograph and transverse section in lower right-hand corner. **(b)** Close-up of a number of large calcified *Archaeoscyphia* specimens.

recognized and described organic buildups from a portion of the El Paso which they named Bat Cave Formation (now McKelligon Canyon Formation). Significantly, they noted that these organic structures were composed principally of stromatolites, but also contained occasional megafossils of solitary corals, bryozoans, gastropods, cephalopods, and trilobites. It was further stated that these fossils occurred both in the organic buildups and in the surrounding limestones. Some of their fossil identifications are in error, and it is most probable that what they regarded as solitary corals are archaeoscyphid sponges, and that the organisms identified as bryozoans can probably be referred to the receptaculitid alga *Calathium.*

The McKelligon Canyon organic buildups are composed principally of mud with relatively common skeletal components. Their skeletal framework is dominated by three primary biotic builders. These are: (1) *Pulchrilamina spinosa* Toomey & Ham, an organism of uncertain biological affinity but possibly related to the coelenterates (the "stromatolitic material" of Cloud & Barnes), (2) the siliceous lithistid sponge *Archaeoscyphia annulata* Cullison, and (3) the upright alga *Calathium* (figs. 6, 7).

It is important to note at this time that the well-known organism in this area, generally referred to by previous workers as *Calathium,* belongs to a different genus. *Calathium,* originally described by Billings (1865) from Newfoundland, differs from our fossils in a significant number of ways. Calathids have received surprisingly little attention until recently. Miagkova (1965) in the Soviet Union described similar fossils under the name *Soanites*; Nitecki (1969) assigned *Calathium* to receptaculitid algae; Church (1974) described the paleoecology of Utah carbonate mounds containing *Calathium;* Alberstadt & Walker (1975) illustrated calathids in detail from the Middle Ordovician reefs in Tennessee; and we are presently preparing a monograph on calathids. Although we are aware that our "*Calathium*" should be renamed, to avoid the introduction of nomenclatural and taxonomic changes we retain the name *Calathium* for this common fossil in our area of study.

Common to the base of many of the larger and better-developed organic buildups are clusters of relatively small digitate stromatolites (fig. 9). We estimate that the mud filling supporting the above three biotic builders constitutes about 60 to 75 per cent of what may be considered as a typical McKelligon Canyon organic buildup.

a

b

FIG. 7. Outcrop photographs of colonies of *Pulchrilamina spinosa* Toomey & Ham from the Lower Ordovician El Paso Group in the principal mound horizon, lower portion of the McKelligon Canyon Formation, in the southern Franklin Mountains at El Paso, far West Texas. (a) Photograph shows the distinctive *Pulchrilamina* laminations, some laminae exhibit surficial silicification; diameter of tape measure is 3 ¾ in. (b) Upper mound surface showing the abundance of *Pulchrilamina*, a colonial organism of uncertain biological affinity; length of hammer is 15 in.

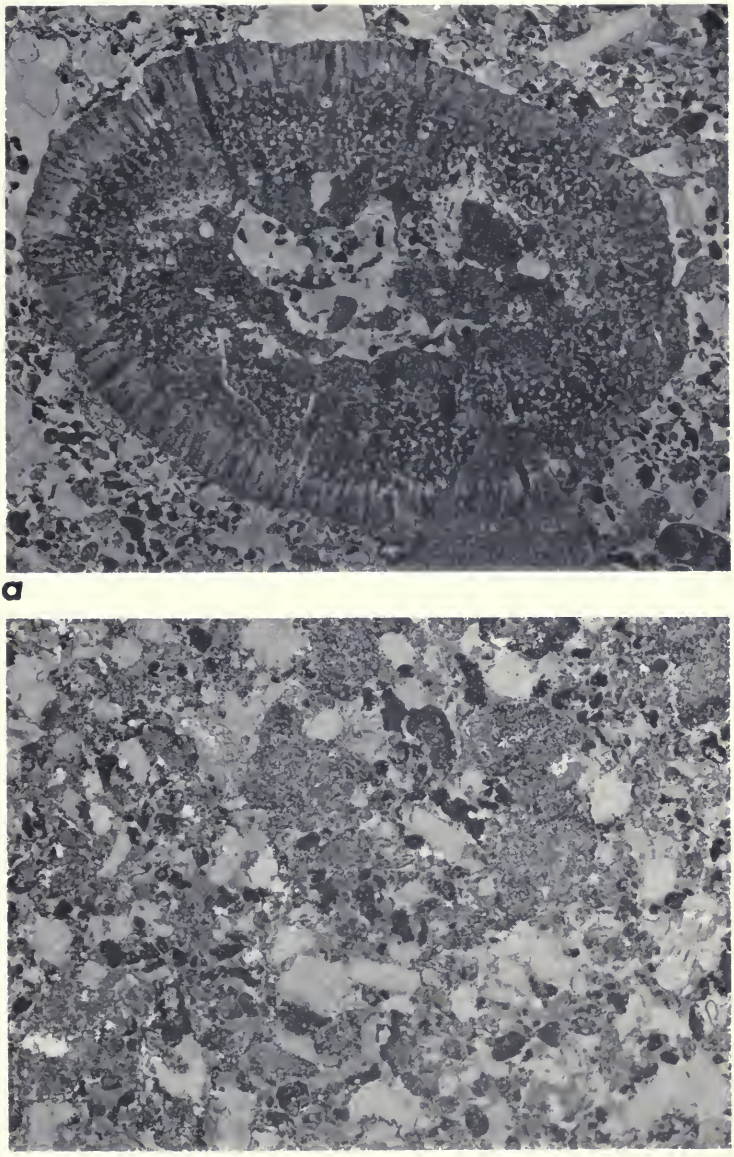
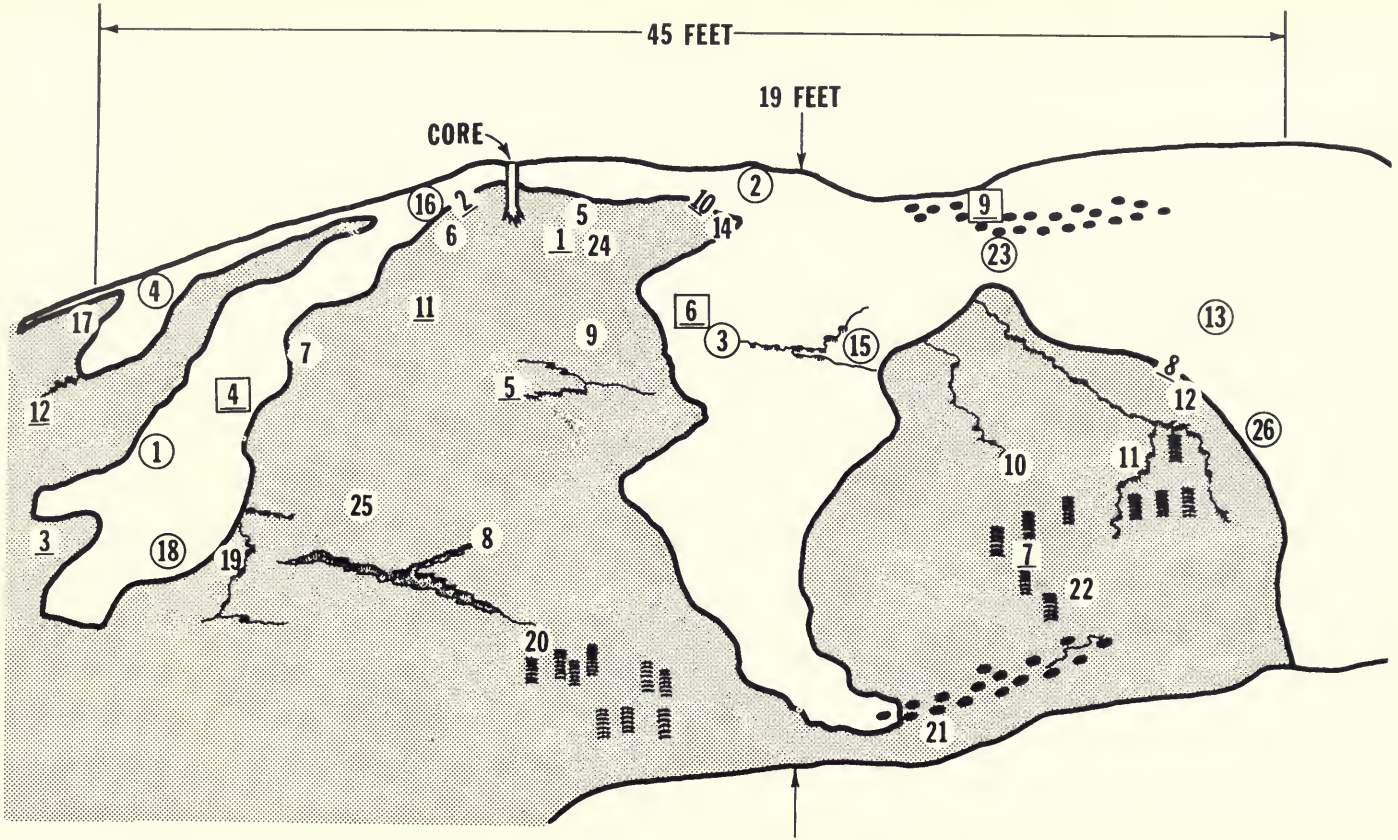



FIG.8. Thin-section photomicrographs (× 4⁹/₁₀) of calcarenitic channel rock from the principal mound horizon in the McKelligon Canyon Formation, southern Franklin Mountains, West Texas. (a) Photomicrograph shows a badly abraded lithistid sponge fragment surrounded by intraclasts (dark grains) and echinodermal debris embedded within a sparry calcite matrix. (b) As above, but showing abundant echinodermal debris; many of the ossicles have pronounced calcite overgrowths.


45 FEET
19 FEET
CORE

Relatively coarse skeletal packstones and grainstones form conspicuous "halos" around some of the organic buildups, and some of the larger and better-developed buildups are cut by channels that have been filled with coarse calcarenitic debris, predominantly echinodermal ossicles, and intraclasts (fig. 8). Some of these channels show pronounced cross-bedded sedimentary structures (fig. 5).

Surrounding the organic buildups, but beyond the calcarenitic "halo," is a sequence of thin, well-bedded carbonates that are different in many features from the moundrock. Whereas the organic buildup is non-bedded and relatively massive, the off-mound rock consists of a series of thin-bedded carbonates that appear, in part, to be cyclic, and that run the gamut from burrowed mudstones to skeletal wackestones. A conspicuous difference is in the overall biotic composition and abundance of the two distinctive rock sequences. The organic buildups are characterized by abundant specimens of the three biotic builders, many of which appear to be in growth position. The off-mound sequence contains fewer representatives of these biotic elements, and these, for the most part, are abraded, broken, or both. The calcarenitic channels commonly contain silicified cephalopod siphuncles, echinodermal ossicles, trilobite debris, intraclasts, and many orthid-type brachiopods. The intermound sequence of thin-bedded carbonates in places contains abundant abraded specimens of an orospirid-type gastropod.

The off-mound thin-bedded carbonates may locally contain larger stacked hemispheroidal-shaped algal stromatolites of very limited extent, contrasting with the small digitate forms at the base of the mounds.

**Moundrock Petrology**—Following the carbonate classification of Dunham (1962), the moundrock is primarily a skeletal wackestone (fig. 10). In some instances the skeletal wackestones grade into a skeletal packstone and boundstone. Intraclasts are common, as are conspicuous organism burrows.

True indication of boundstone is usually present only near the

---

*Opposite:*

FIG. 9. Lechuguilla Mound, McKelligon Canyon Formation, southern Franklin Mountains, West Texas, showing sample control (circles) and location of grid control (squares). Stippled area is moundrock whereas blank area represents channel and intermound rock; blacked-in ellipses represent chert nodules, and stacked layers represent digitate stromatolites. Numbers are not keyed here (from Toomey, 1970).

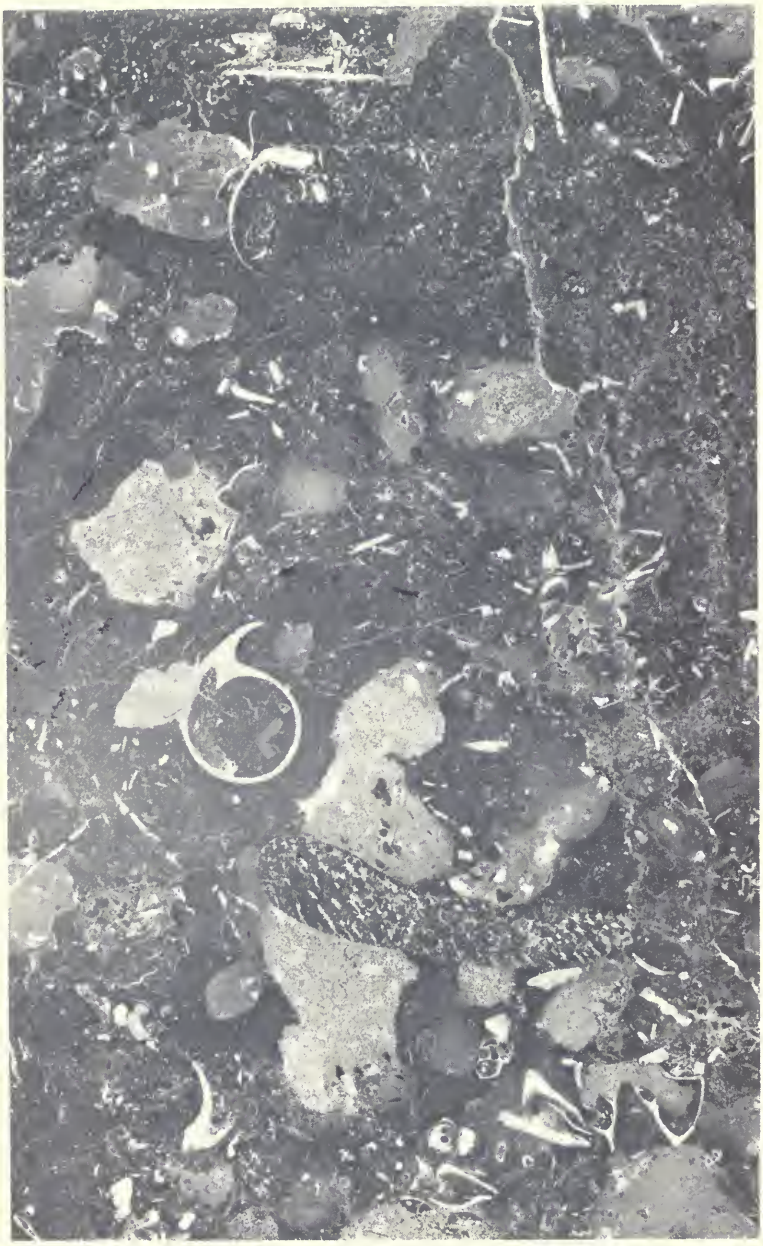


FIG. 10. Thin-section photomicrograph ( × 4) of typical moundrock from the principal McKelligon Canyon Formation mound horizon, southern Franklin Mountains, West Texas. Rock can be classified as a highly burrowed skeletal wackestone (mainly spicules and gastropods) with intraclasts. Note elongated intraclast composed of a fragment of a lithistid sponge meshwork.

tops of the organic buildups where much *Pulchrilamina* is found (fig. 11). As will be noted, when boundstone becomes dominant the organic buildup has attained its climax stage of development. In general, the moundrock shows patchy areas of algal binding throughout.

Skeletal grains may comprise up to 25 per cent of the moundrock; four types are relatively abundant and scattered throughout the organic buildups. These are: (1) pelmatozoan ossicles, (2) spicules and spines, (3) gastropod, brachiopod, and trilobite debris, and (4) algal? or problematical remains.

The crinoidal ossicles are identified by their characteristic petrographic attribute of reacting as a single unit crystal under crossed-nicols. In a few thin-sections diplopores have been recognized, indicating that some cystoids were present. Most of the echinodermal debris appears to be derived from crinoids. Many of the echinodermal grains have a dark circumscribed rim of cryptocrystalline calcite (micrite envelope) and show evidence of extensive organic borings. This boring has been attributed to the action of the perforating and boring blue-green alga *Girvanella* (Klement & Toomey, 1967).

Spicules and spines appear to be derived from the three primary organic constituents: *Pulchrilamina*, *Archaeoscyphia*, and *Calathium*. Much of the skeletal debris identified as spines apparently can be attributed to *Pulchrilamina*. The upper surface of this laminated colonial form contains many spines (figs. 12, 13), and these are abundantly scattered throughout the moundrock. In some instances, threads of the alga *Girvanella* are present on the individual laminae of *Pulchrilamina*. Lithistid sponge spicules, and various other spicular forms, are rather common in the moundrock and many can be attributed to *Archaeoscyphia* (fig. 14), and other forms (fig. 15). On Lechuguilla Mound whole specimens of *Archaeoscyphia* are up to 10 in. in length and 5 in. in width. A few specimens even have their root systems preserved, and many are found in what is believed to be *in situ* growth position. Whole-specimens of the receptaculitid alga *Calathium* average about 5 in. in length and 3 in. in width; root systems are relatively common. *Calathium* is an abundant organic contributor to the mound, and many of the fossil specimens are thought to be preserved in position of growth.

a

b

Skeletal debris identified as belonging to brachiopods, gastropods, and trilobites are conspicuous grain constituents within the organic buildups. Gastropods, especially the orospirid-type, are most abundant (fig. 15) and one of the most easily recognizable skeletal grains. Most are whole specimens. Trilobite debris on the buildups is rather patchy, but can be locally abundant and some appear to be extensively bored (Toomey, 1970, fig. 11a). Brachiopod debris is not as common as gastropod and trilobite material, but formic acid residues of moundrock have yielded many silicified specimens of the orthid brachiopods *Finkelnburgia* sp. cf. *F. crassicostellata* Cooper, and *Oligorthis arbucklensis* Urich & Cooper (figs. 16, 17).

Skeletal grains regarded as being derived from algae or *problematica* can be placed into two groups: (1) tubular filaments with a diameter from 10 to 16 $\mu$ and identified as the blue-green alga *Girvanella*, and (2) a problematical tubular skeletal constituent with a dark central canal and a characteristic radial-hyaline wall microstructure that is identified as *Nuia siberica* Maslov (Toomey & Klement, 1966). This form may be related to the algae, but is best regarded as a *problematica*. Both these grain types are common in moundrock. The tubules of *Girvanella* are most commonly seen as perforating and boring features on many of the skeletal and non-skeletal grains (fig. 18a).

The dominant non-skeletal grains found in the moundrock are intraclasts. Usually, intraclasts are more common in those samples taken from near the tops of the organic buildups. The largest clast observed in the McKelligon Canyon organic buildups is 15 mm. in length and 8 mm. in width. Most intraclasts are relatively small, fairly well-rounded, and many appear to have pronounced marginal corrosion rims of what appears to be recrystallized *Girvanella* tubules (fig. 18b).

---

*Opposite:*

FIG. 11. Outcrop photographs of small organic buildups in the McKelligon Canyon Formation, southern Franklin Mountains, West Texas. (a) Note that the moundrock is of lighter color than the surrounding rock and that the upper one-half of the buildup is composed primarily of the laminated organism *Pulchrilamina spinosa* Toomey & Ham. (b) Close-up view of a small organic buildup showing a distinctive growth sequence consisting of a basal foundational unit of organism burrowed dolomite, overlain by moundrock first containing abundant *Calathium* and *Archaeoscyphia*, and, finally, dominated by *Pulchrilamina*. Note the very sharp contact between the moundrock and the surrounding darker-colored calcarenite containing conspicuous silicified cephalopod siphuncles.

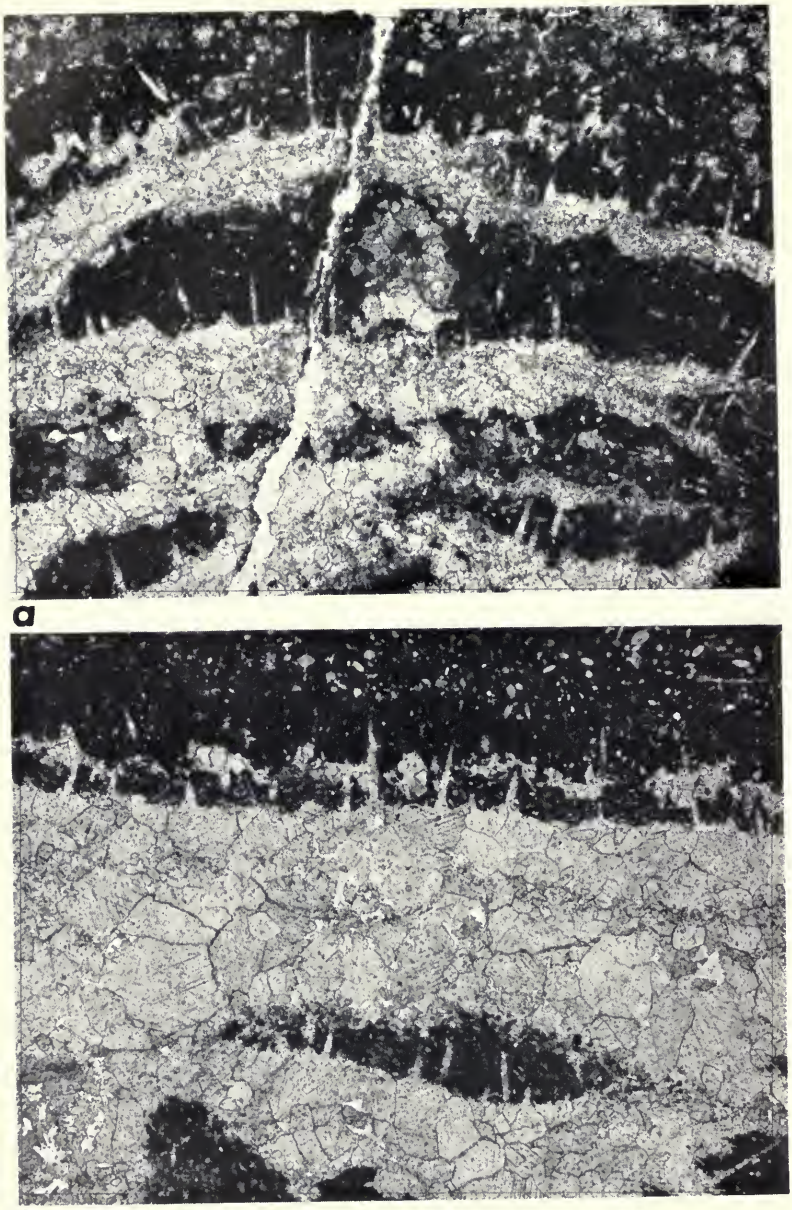



FIG. 12. Low-power, thin-section photomicrographs of *Pulchrilamina spinosa* Toomey & Ham from the main mound horizon in the lower portion of the McKelligon Canyon Formation, southern Franklin Mountains at El Paso, West Texas. **(a)** Photomicrograph ( × 20) showing a few spinose laminae with entrapped mud layers between the laminae. **(b)** Photomicrograph ( × 30) showing that the laminae have been totally recrystallized to form mosaic calcite.

FIG. 13. Thin-section photomicrographs (×80) of the upper laminae of *Pulchrilamina spinosa* Toomey & Ham from the principal mound horizon in the lower portion of the McKelligon Canyon Formation, southern Franklin Mountains at El Paso. (a, b) The irregular distribution of the spines and entrapped mud on the laminae.

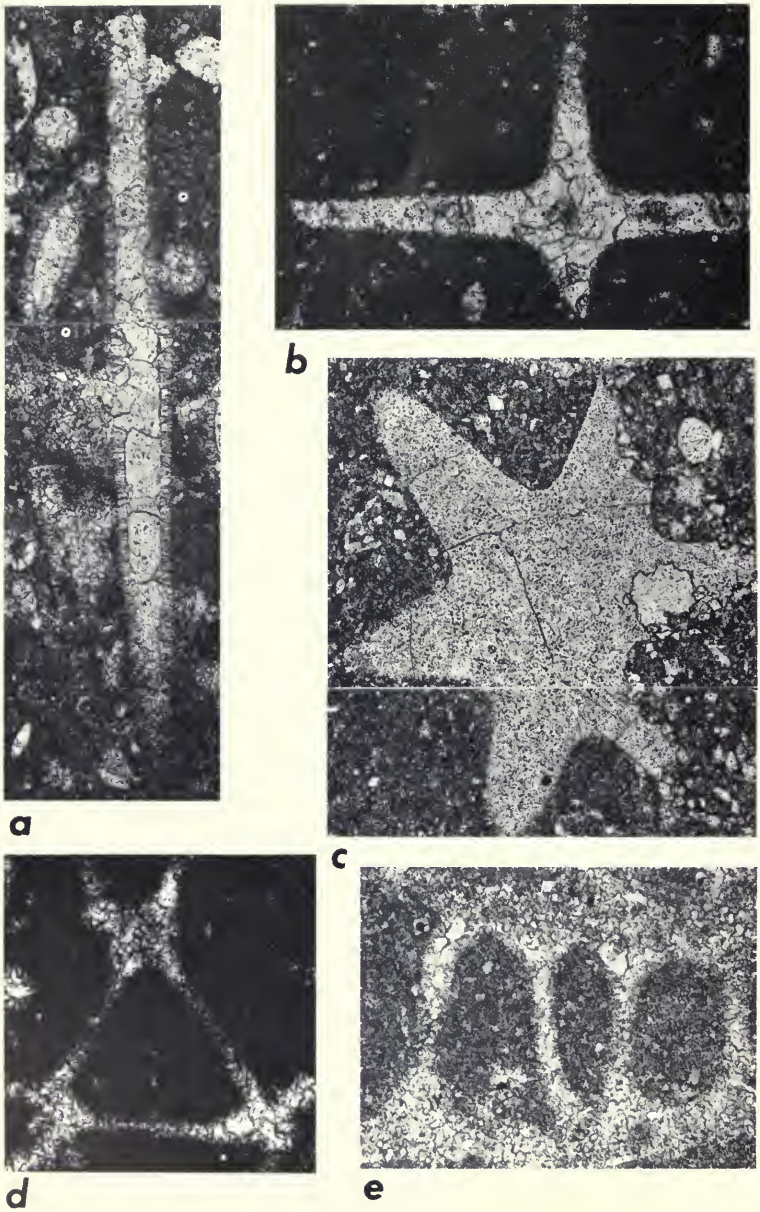
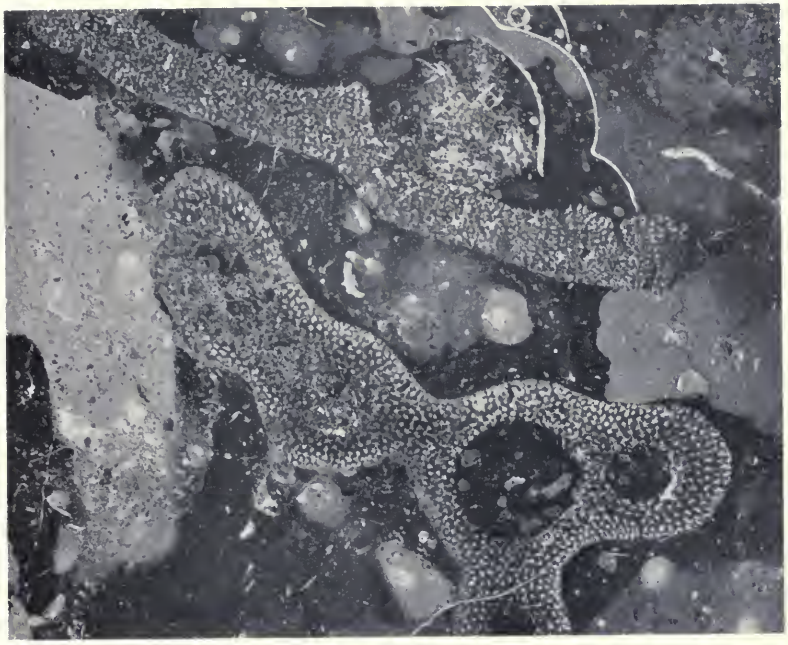
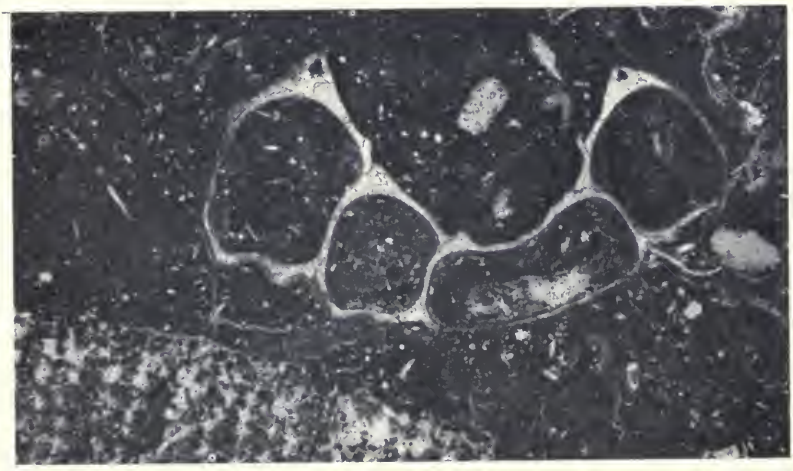



FIG. 14. Thin-section photomicrographs (×86) of various sponge spicules commonly found in the moundrock of the McKelligon Canyon Formation, southern Franklin Mountains, West Texas. (a) Typical monaxon spicules showing the distinctive axial canal. (b) Portion of a tetraxon spicule. (c) A star-shaped spicule. (d, e) Lithistid sponge spicules (desmas).



a



b

FIG. 15. Photomicrographs of various organisms occurring in typical moundrock common to the principal mound horizons in the McKelligon Canyon Formation, southern Franklin Mountains, West Texas. (a) Burrowed skeletal wackestone (×3) with well-preserved lithistid sponges and trilobite shell fragments. (b) Skeletal wackestone (× 10) with conspicuous orospirid-type gastropod and a lithistid sponge fragment in lower left-hand corner of photograph.

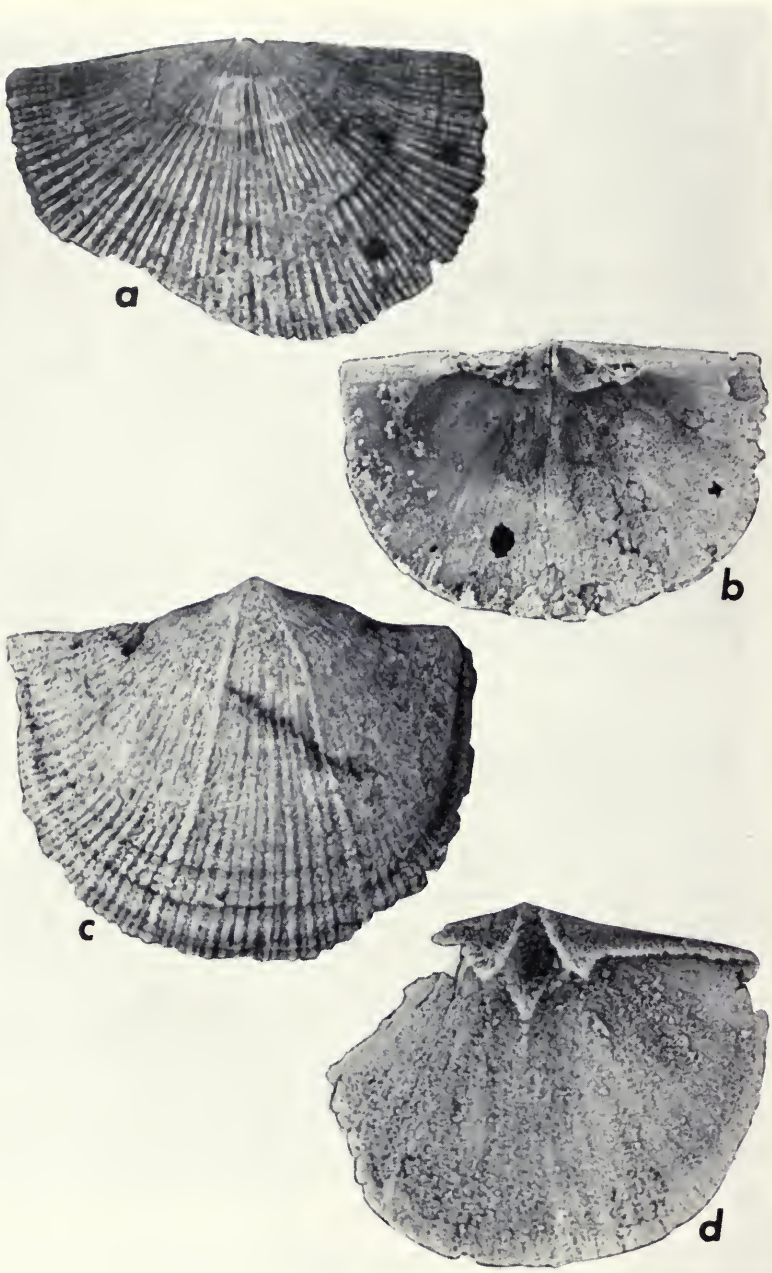



FIG. 16. Silicified brachiopods derived from acid etching of McKelligon Canyon Formation rock, southern Franklin Mountains, El Paso, West Texas. (a-d) Orthid brachiopod *Finkelnburgia* sp. cf. *F. crassicostellata* Cooper ( × 4): (a) dorsal valve exterior; (b) dorsal valve interior; (c) ventral valve exterior; (d) ventral valve interior.

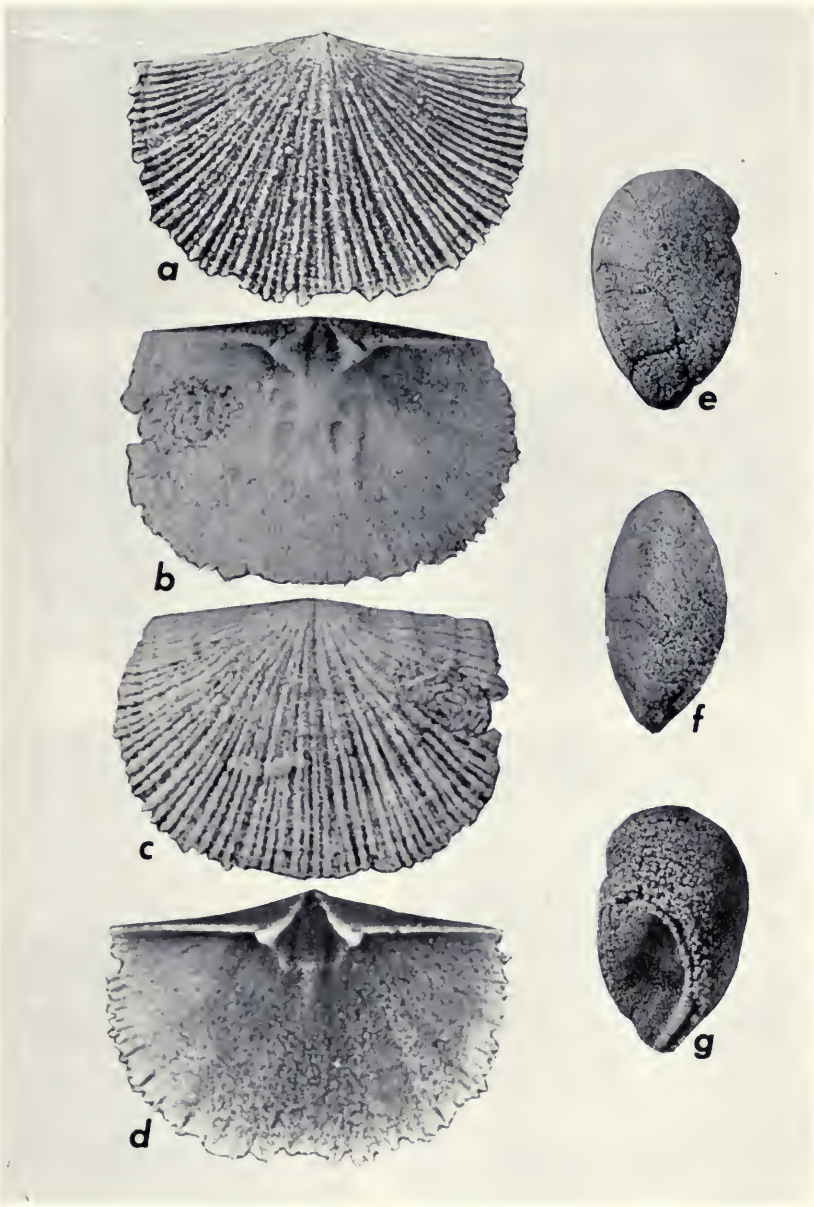



FIG. 17. Silicified fossils derived from acid etching of McKelligon Canyon Formation rock, southern Franklin Mountains, El Paso, West Texas. **(a-d)** Orthid brachiopod *Oligorthis arbucklensis* Ulrich & Cooper (× 4⅜): (a) ventral valve exterior; (b) dorsal valve interior; (c) dorsal valve exterior; (d) ventral valve interior. **(e-g)** Gastropod opercula, *Ceratopea capuliformis* Oder (× 2⅛): (e) dorsal view; (f) ventral view; (g) carinal view.

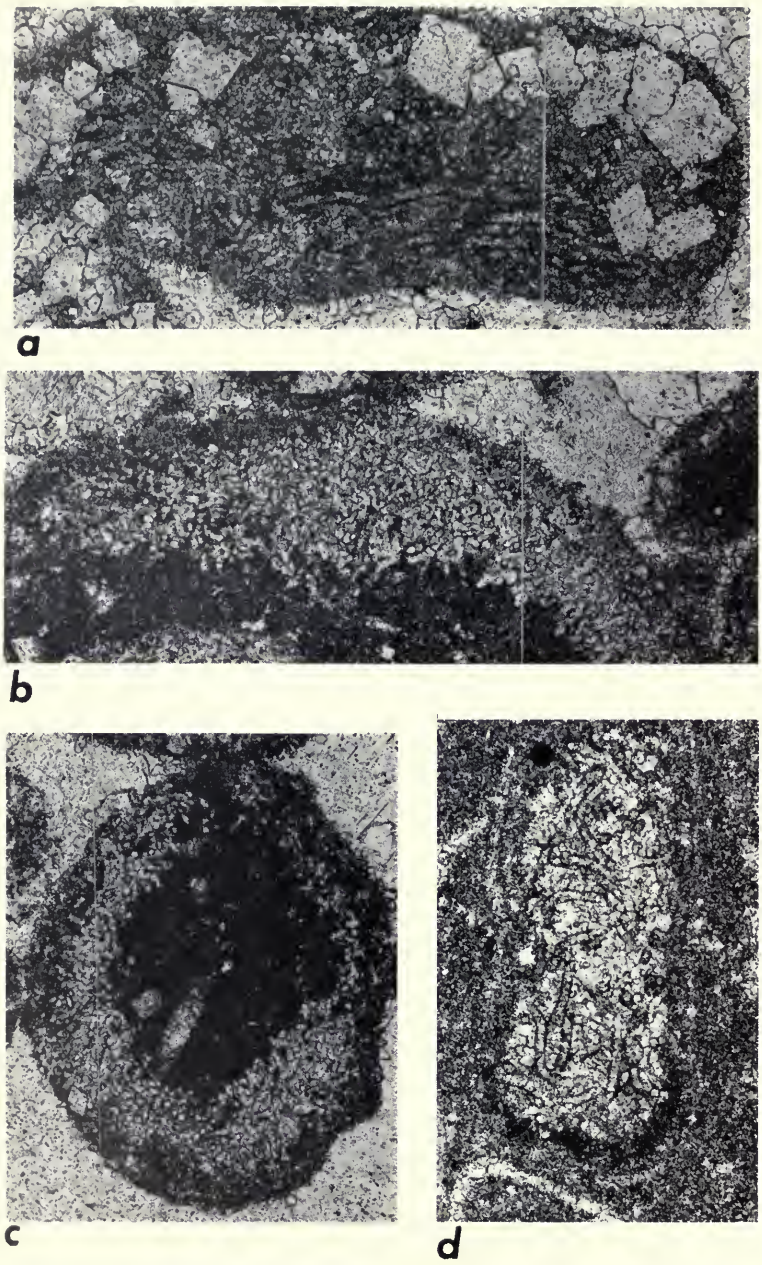



FIG. 18. Thin-section photomicrographs ( × 80) of the boring effects and remains of the blue-green alga *Girvanella*. **(a,d)** Small nodules composed of *Girvanella* tubules. **(b,c)** intraclasts with pronounced bored corrosion rims attributed to the action of the boring and perforating alga *Girvanella*.

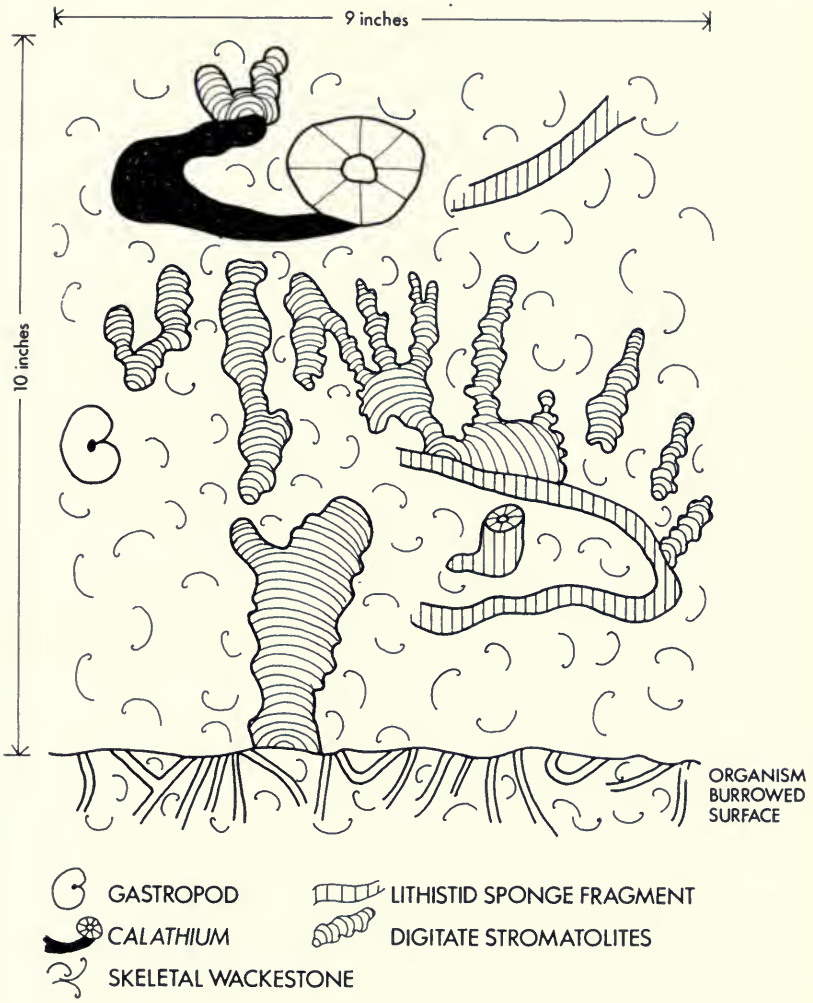



FIG. 19. Field sketch showing small-scale digitate stromatolite colonies encrusting mound foundation and tumbled sponge fragments, McKelligon Canyon moundrock, southern Franklin Mountains, West Texas.

Most of the thin-sections prepared from moundrock show evidence of organism burrowing. This is best shown by patches of swirled skeletal debris and burrows, some of which still contain fecal pellets. The organism burrows may be up to an inch in width, usually have a sparry calcite center (which can be a single large crystal), are are usually surrounded by progressively finer dolomite

rhombs. The outer edges of the organism burrows may be rimmed by larger dolomite rhombs.

Colonies of floating digitate stromatolites are usually present only near the base of the organic buildup. Individual "fingers" average one-half inch in diameter, and colonies are approximately 3 in. in height. In many instances, these small digitate stromatolites encrust what appear to be tumbled fragments of both *Archaeoscyphia* and *Calathium* (fig. 19). Petrographically, the stromatolites appear as thin laminae of dolomite rhombs separated by thicker layers of mud, and on occasion some *Girvanella* threads are entwined among the dolomite rhombs.

Dolomite rhombs occur in the moundrock as scattered rhombs floating in a muddy matrix. The sizes of the dolomite rhombs vary appreciably although most are under 100 $\mu$ in diameter.

Ropey chert nodules occur on Lechuguilla Mound (fig. 19). The nodules are composed of cryptocrystalline chert with some fossil ghost remnants, and scattered floating dolomite rhombs (Toomey, 1970, p. 1,324). The chert is of secondary origin, and is rare within any particular mound. Chert is much more common in the intermound beds where it is in part spicular.

In order to determine the gross volumetric percentage of skeletal-nonskeletal grains present on Lechuguilla Mound, a 1-ft. by 1-ft. frame strung with wire to form a grid of 1-in. squares was used in making point-counts of the various grains present over a representative area of the mound (position of grid-counts shown on Figure 19). The results of six grid controlled areas of moundrock indicates that of 59.9 per cent of total average skeletal debris, 51.3 per cent is composed of the remains of the three primary organic components: *Archaeoscyphia* (29.9 per cent), *Calathium* (15.3 per cent), and *Pulchrilamina* (15.1 per cent). The non-skeletal mound components are mudstone (38.1 per cent) and intraclasts (1.8 per cent), without significant variation between succeeding grids.

**Channel Rock Petrology.**—As noted above, channels cutting down into the organic buildup are well developed on the larger mounds. These channels are usually not more than 2 ft. in width, and the deepest one observed to date cuts into moundrock for a depth of 12 ft. The channels are of darker-color and stand out sharply from the surrounding lighter-colored moundrock. The channels are filled with intraclasts, broken and abraded sponges, cephalopod siphuncles, and echinodermal debris, much of it silicified. Some

layers of small spicular chert nodules are also present in the channels.

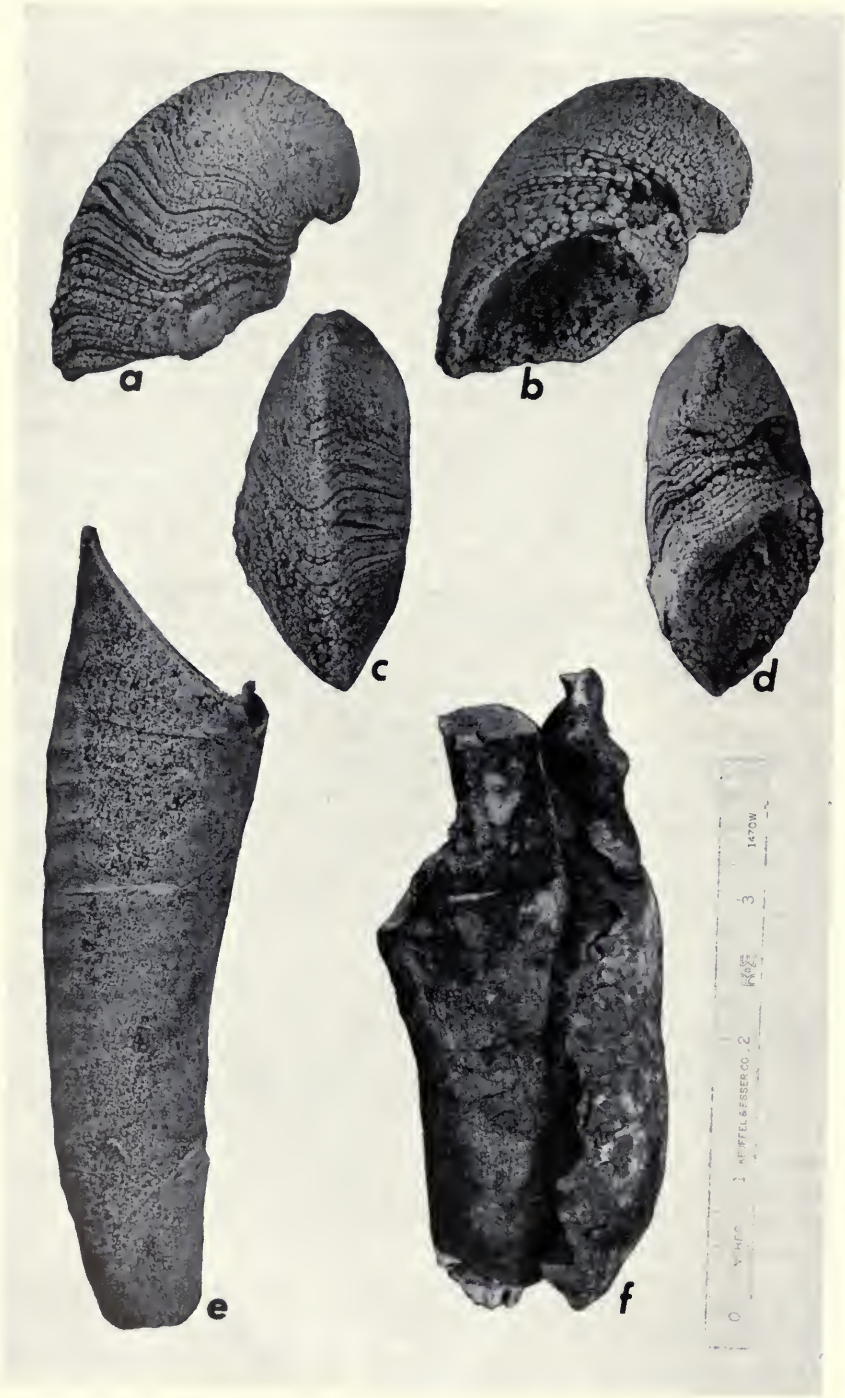
Following the classification of Dunham (1962), the channel rock may be described as an intraclastic, skeletal grainstone (fig. 8). Intraclasts are very abundant, well rounded, and many of them are circumscribed by micrite envelopes showing conspicuous algal borings, in part recrystallized (fig. 18). Some of the *Girvanella* borings are in-filled with dark cryptocrystalline micrite. Many of the echinodermal ossicles are likewise affected; others show pronounced calcite overgrowths. The channel rock matrix consists of relatively coarse sparry calcite, although this grades into scattered patches of interlocking dolomite rhombs usually under 200 $\mu$ in diameter. Scattered dolomite rhombs are commonly seen within many intraclasts and some intraclasts appear to have been literally "eaten up" by dolomite rhomb encroachment (Toomey, 1970, fig. 12G, p. 1,327).

Thin-sections prepared from the channels cutting the McKelligon Canyon organic buildups show the channel sediment to have been the most completely winnowed of any mud component; the rock can be described as an intraclastic skeletal packstone-grainstone.

Bored *Nuia* grains, *Girvanella* tubules, a few trilobite fragments, gastropods, brachiopods, and spicules are also present within many of the intraclasts. Broken and abraded fragments of some of the larger fossils, in particular *Archaeoscyphia* and *Calathium,* are abundant in those areas of sharp contact between mound and channel rock, and here silicification of these two megafossils, along with cephalopod siphuncles, is most apparent.

Results of three grid-controlled areas of channel rock on Lechuguilla Mound (fig. 9) show that of the three principal biotic contributors, *Pulchrilamina* is absent, *Archaeoscyphia* is reduced to 13.2 per cent and *Calathium* is much reduced, down to less than 1 per cent. Perhaps more significant, is the increased abundance of intraclasts (from 1.8 per cent to 47.2 per cent). The total percent of skeletal material is 44.2 per cent compared to 59.9 per cent in the moundrock, whereas non-skeletal material is 55.7 per cent, compared to 39.9 per cent in the moundrock; the differences are appreciable.

**Mound Foundation.**—Most of the McKelligon Canyon organic buildups present in the southern Franklin Mountains of West Texas, and in other mountain ranges of southern New Mexico, ap-


a
b
c
d
e
f

pear to rest on a similar rock type. This foundational rock unit is usually a buff to mustard-colored, mottled, intensely burrowed, dolomitized, skeletal wackestone. Dolomite rhombs of less than 100 $\mu$ are abundantly scattered throughout the foundational unit, whereas dolomite rhombs of larger size (commonly 200-300 $\mu$) usually fill the organism burrows. Skeletal debris in this unit consists of scattered echinodermal ossicles, spicules (some of which are definitely sponge derived), the problematical micro-organism *Nuia*, and trilobite fragments.

**Intermound Rock.**—The rock sequence usually occurring between the organic buildups consists of a possibly cyclic series of thin, well-bedded carbonates that can be described as : (1) buff-colored, mottled, burrowed, dolomitized skeletal wackestones (mound foundation); (2) intraclastic, gastropodal packstones; and (3) intraclastic, echinodermal wackestones/packstones/grainstones. One occurrence, close to Lechuguilla Mound, of stromatolites of the stacked-hemispheroidal type was also observed. Stromatolites *per se* are, for the most part, rare.

Fossil constituents within the intermound rocks consist primarily of small turbinate-shaped gastropods associated with much echinodermal debris. Larger megafossils, such as sponges, *Calathium*, *Pulchrilamina*, and cephalopods, are rare within the intermound sequence. Layers of ropey-type chert nodules, sometimes containing abundant sponge spicules, occur sporadically throughout the intermound rocks.

**Occurrence of *Ceratopea* within the Mound Interval.**—The fossil *Ceratopea* is a unique form that occurs in many Lower Ordovician localities (Yochelson & Bridge, 1957) and is considered to be a gastropod operculum. Two species of *Ceratopea* are present in the McKelligon Canyon Formation of the southern Franklin Mountains of West Texas. These are *Ceratopea capuliformis* Oder (fig. 17e-g), and *C. incurvata* Yochelson & Bridge (fig. 20a-d). Both forms are

---

*Opposite:*

FIG. 20. Silicified fossils derived from acid etching of McKelligon Canyon Formation rock, southern Franklin mountains at El Paso, far West Texas. (a-d) Gastropod opercula ( × 2) of *Ceratopea incurvata* Yochelson & Bridge from an interval 179-182 ft. above the base of the formation: (a) dorsal view; (b) ventral view; (c) carinal view; (d) umbilical view. (e) Nautiloid cephalopod siphuncle of the McQueenoceroid-type, common throughout the McKelligon Canyon Formation. (f) Chert nodule preservation of the spongocoel and a portion of the wall of the lithistid sponge *Archaeoscyphia*.

found in a single, massive, 5-ft. bed of skeletal wackestone that does not carry organic buildups (fig. 21). Several *Ceratopea* are widely distributed geographically and occur within well-defined stratigraphic horizons; therefore, they are valuable guides for interregional correlation. Their stratigraphic value is enhanced because fossils in Lower Ordovician strata are neither very abundant nor common. Most of the *Ceratopea* are silicified and can be easily freed from the matrix by acid etching.

The smaller species of gastropod opercula, *Ceratopea capuliformis* Order, common in the lower Kindblade Formation of southern Oklahoma, is characteristic of the Kingsport Formation in Tennessee, and is present in the Rich Fountain Formation of Missouri. This species is also common in the lower portion of the Honeycut Formation of central Texas (Yochelson & Bridge, 1957, p. 294).

Cloud & Barnes (1948, p. 365) reported the occurrence of *Ceratopea* cf. *C.* sp. 5 from subunit $B_1$ interval 15 in the southern Franklin Mountains of West Texas. They did not indicate that it came from a mound horizon, and we would think that both occurrences are one and the same. Later, Yochelson & Bridge (1957, p. 297) placed this form under *Ceratopea incurvata.*

More recently, Yochelson (1975, p. 447) presented interesting paleoecological observations in which he suggested that *Ceratopea* may have lived in an indigenous stressed environment, and may have been essentially the only shelled invertebrate present. Presumably, these gastropods grazed upon algal mats and algal mounds growing in areas of water slightly more saline than open marine waters. Penecontemporaneous silicification of calcareous opercula on the Ordovician sea bottom was postulated.

This rather minor bed occurring near the middle of the McKelligon Canyon Formation, and containing many specimens of the two species of *Ceratopea,* is unique in that no other obvious megafossils are observed. The bed is highly burrowed, and the burrows themselves are a mustard color. Thin-section examination indicates that the burrows contain fecal pellets and abundant dolomite rhombs. Still, it should be emphasized that no *Ceratopea* have been found on an actual organic buildup within the McKelligon Canyon Formation.

**Conodonts.**—From formic acid residues of large blocks of moundrock, a total of 1,530 identifiable conodonts were obtained (table 1). These were identified by Ethington, who recognized 35 different

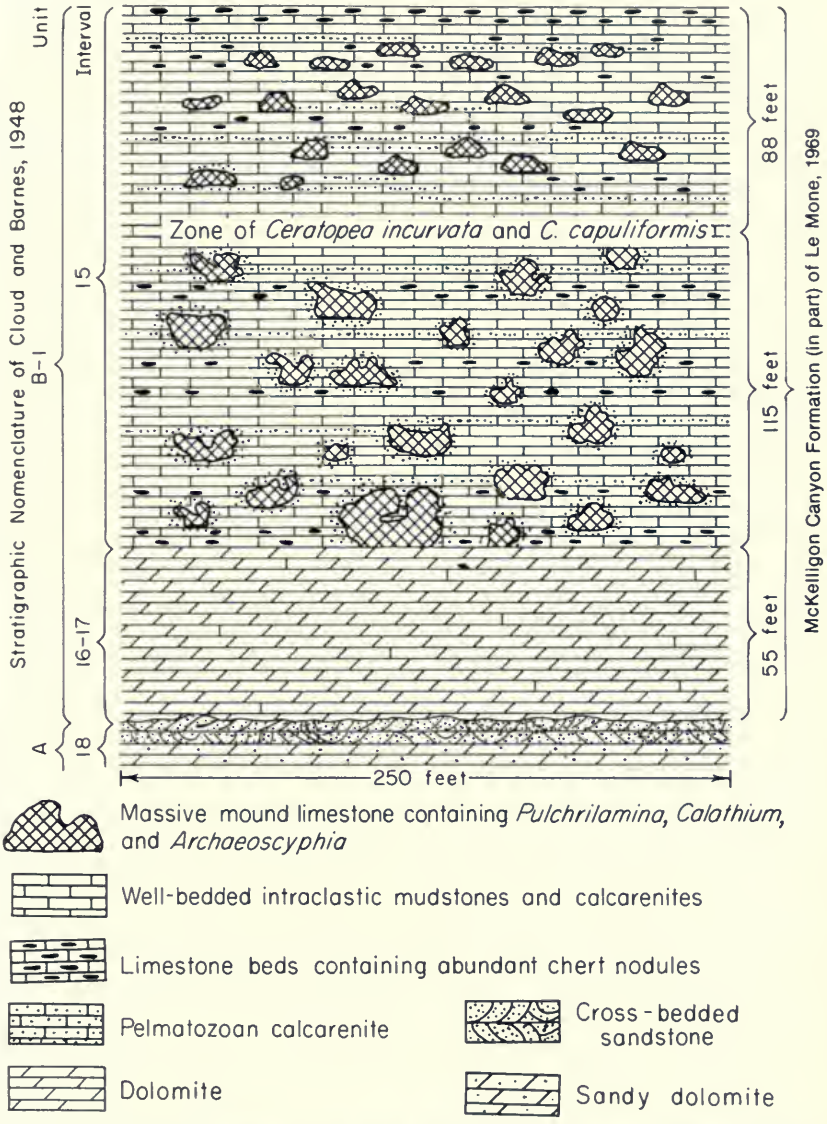



FIG. 21. Schematic diagram showing mound occurrences and position of thin *Ceratopea* zone present in the McKelligon Canyon Formation, southern Franklin Mountains, West Texas (slightly modified from Toomey & Ham, 1967).

TABLE 1. Conodont assemblages from the mound horizons in the lower McKelligon Canyon Formation of the El Paso Group, southern Franklin Mountains, far West Texas.

| SPECIES | NUMBER OF SPECIMENS |
|---|---|
| 1. *Acodus* aff. *A. deltatus* Lindstrom | |
| acodiform-element | 51 |
| distacodiform-element | 20 |
| drepanodiform-element | 7 |
| oistodiform-element | 3 |
| trichonodelliform-element | 23 |
| 2. *A. russoi* Serpagli | |
| tetraprioniodiformis-element | 1 |
| trichonodelliform-element | 1 |
| 3. *Drepanodus arcuatus* Pander | |
| arcuatiform-element | 20 |
| oistodiform-element | 29 |
| sculponeaform-element | 4 |
| 4. *"D." subarcuatus* Furnish | 211 |
| 5. *D. suberectus* (Branson & Mehl) | 5 |
| 6. drepanodiform-elements | 93 |
| 7. oistodiform-elements | 79 |
| 8. *Drepanoistodus forceps* (Lindstrom) | |
| oistodiform-element | 1 |
| 9. ?*Microzarkodina* sp. | |
| oistodiform-element | 15 |
| 10. ?*Juanognathus* sp. | 3 |
| 11. *Oistodus longiramis* Lindstrom | 1 |
| 12. *Oneotodus simplex* (Furnish) | 116 |
| 13. oneotodiform-element | 1 |
| 14. Aff. *Paltodus inconstans* Lindstrom | |
| oistodiform-element | 35 |
| 15. paltodiform-elements | 11 |
| 16. *Paroistodus originalis* (Sergeeva) | |
| drepanodiform-element | 2 |
| oistodiform-element | 1 |
| 17. *P. proteus* (Lindstrom) | |
| drepanodiform-element | 5 |
| oistodiform-element | 18 |
| 18. Aff. *Scandodus furnishi* Lindstrom | 1 |
| 19. Aff. *"S." robustus* Serpagli | 8 |
| 20. *S. toomeyi* (Ethington & Clark) | 24 |
| 21. scandodiform-elements | 4 |
| 22. *Scolopodus filosus* Ethington & Clark | 43 |
| 23. *S. gracilis* Ethington & Clark | 89 |
| 24. *S. iowensis* (Furnish) | 3 |
| 25. *S. quadraplicatus* Branson & Mehl | 230 |
| 26. Aff. *S. rex* Lindstrom | 13 |

Table 1 — *continued*

| SPECIES | NUMBER OF SPECIMENS |
|---|---|
| 27. *S. staufferi* (Furnish) | 78 |
| 28. *S. triangularis* Ethington & Clark | 70 |
| 29. *S. triplicatus* Ethington & Clark | 181 |
| 30. *Ulrichodina abnormalis* (Branson & Mehl) | 3 |
| 31. *U. deflexa* Furnish | 15 |
| 32. *U. wisconsinensis* Furnish | 2 |
| 33. *U.* sp. | 2 |
| 34. *Walliserodus comptus* (Branson & Mehl) quadricostate-element | 1 |
| 35. New genus and species belodiniform-element | 4 |
| eobelodiniform-element | 2 |
| ?prioniodiform-element | 1 |
| Total number of specimens | 1,530 |

forms, mostly simple cones. Ethington & Clark (1964) formally described much of this microfauna previously, and at this time noted that conodonts from the middle and middle upper part of the El Paso Group are younger than Early Ordovician faunas previously described in this country.

**Role of *Pulchrilamina* in West Texas Organic Buildups.** — A mound-building organism, *Pulchrilamina spinosa*, was described from the Lower Ordovician strata of West Texas and southern Oklahoma by Toomey & Ham (1967). In their description they noted that *Pulchrilamina* was of uncertain biological affinity, but possibly related to the coelenterates. It is characterized by its massive colonial growth form and laminated structure (fig. 7). Randomly distributed hollow spines of varying size on the upper surfaces of the laminae are an especially noteworthy feature, but these distinctive microstructures can only be seen in thin-section (figs. 12, 13). Superficially, *Pulchrilamina* does show some resemblance to stromatolites. However, the alternating, curved, spiny layers of mosaic calcite are interpreted as representing recrystallized calcium carbonate that had been originally secreted by a colonial organism. *Pulchrilamina* also entrapped suspended muddy sediment between its spiny layers, as shown by the dark matrix in the photomicrographs of specimens illustrated on Figure 12. This possibly coelenterate-like organism, therefore, shares with

stromatolites the feature of sediment entrapment, but differs completely from algal stromatolites in erecting its own colonial form by secretion of skeletal carbonate.

Maximum dimensions of the *Pulchrilamina* colonies are approximately 20 in. high and 10 in. wide. As the characteristic spines are only visible in thin-section, the identifying field characteristics of the organism are its relatively large size and slightly-irregular-to-wavy laminations, which are convex upward where the organism is in position of growth.

The occurrence and distribution of *Pulchrilamina* on the McKelligon Canyon Formation organic buildups appears to have a distinct paleoecological significance. *Pulchrilamina* colonies are only abundant, and dominant, on the tops of the organic buildups (fig. 11). In fact, no *Pulchrilamina* colonies are found until the organic buildup has attained what we have considered to be its climax stage of development. In essence, with the occurrence and abundance of *Pulchrilamina* colonies, the organic buildup as such ceases to grow. Accordingly, the uppermost surface of McKelligon Canyon Formation organic buildups is usually dominated by *Pulchrilamina* colonies, with no other apparent organism in abundance. This relationship of sediment-binding colonial organisms occurring and dominating the tops of organic buildups seems to occur similarly in Middle Ordovician (Chazyan) organic buildups in the Lake Champlain region of the northeastern United States (Pitcher, 1964, p. 659). Here, in morphologically similar, though temporally younger organic buildups, abundant stromotoporoids occupy the same relative position on the buildups, and in both instances are regarded as the dominant faunal elements of the climax organic buildup community.

**Growth and Development of a McKelligon Canyon Formation Organic Buildup.**—It is believed that the organic builups so commonly present in the McKelligon Formation of the southern Franklin Mountains of West Texas, and in other mountain ranges of southern New Mexico, grew and developed in relatively shallow waters of a vast epicontinental sea that covered the region during this time. It is probable that a regional shoreline existed some distance to the east as an extension of the Pedernal Landmass (Diablo Arch), as postulated by Lucia (1969). In the vicinity of the southern Franklin Mountains, Early Ordovician highlands of Precambrian rock, specifically Thunderbird Mountain, probably existed as isolated islands of rhyolite on which El Paso Group

sediments onlap (LeMone, 1967). In addition, at Capital Dome in the Florida Mountains, about 60 miles to the west-northwest of Thunderbird Mountain, there are Precambrian hills with up to 125 ft. of relief protruding up into the Lower Ordovician beds above valleys filled with Bliss Sandstone (Kottlowski et al., 1969, p. 136). These islands of Precambrian rock, such as Thunderbird Mountain and Florida Hills, probably provided detritus to the Early Ordovician seas of the immediate region.

Detailed examination of Lechuiguilla Mound, the largest mound found to-date in the southern Franklin Mountains, reveals that at least six important and recognizable growth stages probably occurred during the depositional history of this particular organic buildup (fig. 22). Even in the smaller-sized organic buildups of the McKelligon Canyon Formation, the main growth stages can sometimes be recognized, i.e., see Figure 11b.

Within the shallow-water subtidal zone, on a foundational substrate of organism burrowed mud, now dolomitized, a pioneer colony (Stage I) consisting of scattered clusters or clumps of organic growth began to develop. This initial biotic community appears to have consisted of rooted echinoderms, occasional sponges (*Archaeoscyphia),* scattered algal growth *(Calathium),* some clusters of orthid brachiopods *(Finkelnburgia* and *Oligorthis),* and sparse trilobites. As a pioneer colony it perpetuated itself by clustering with similar biotic entities. With time, some biotic components died and were essentially buried in place. As the organic buildup enlarged and grew upward, keeping pace with sedimentation, the initial pioneer colony evolved into a more diverse biotically mature community (Stage II). At this point of evolvement, the biotic associations became more varied, consisting of digitate stromatolitic colonies, other algae and *problematica (Girvanella* and *Nuia),* more *Archaeoscyphia, Calathium,* rooted echinoderms, orthid brachiopods, orospirid gastropods, cephalopods, and trilobites. Significantly, scattered colonies of the colonial organism *Pulchrilamina* entered the assemblage at this time. Stage III appears to be the culmination of the organic buildup, with the development of what we have called the climax community. This is characterized by the abundance and rise to dominance of the colonial, questionable coelenterate *Pulchrilamina.* Biotic components that were common in Stage II time have given way to the predominance of *Pulchrilamina,* although some scattered sponges and algae are apparent.

During the first three stages of organic buildup accretion, skeletal

debris was concurrently being shed within and around the mound, due primarily to normal biotic attrition. As the organic buildup was evolving, relief on it at any one time was probably only a few feet. It is thought that Lechuguilla Mound, and others present in the McKelligon Canyon Formation, were probably only low-relief, domical features.

Growing within the subtidal zone, Lechuguilla Mound was undoubtedly affected by sea level changes. During Stage IV, as postulated, sea level changed and the mound structure could have been subaerially exposed along the upper surface of the buildup. This exposure would have effectively terminated mound growth. Surrounding skeletal debris shed from the buildup would also be exposed during this stage. If subaerial exposure continued, as postulated in Stage V, coupled with intertidal erosion, three significant events would have occurred: (1) cessation of mound growth, (2) probable hardening of the mound surface, and (3) concurrent intertidal erosion of the mound, producing channels. Stage VI is the postulated culminating event in the history of the McKelligon Canyon organic buildups. This event occurred with a general rise in sea level and the resultant resubmergence of the eroded mound mass within shallow intertidal-to-subtidal waters concurrent with overall transgression. Deposition of the skeletal calcarenites, composed primarily of echinodermal debris and intraclasts (both thought to have been derived from eroded moundrock) and from sediments immediately adjacent to the mound, filled in the erosion-induced irregularities on and around the mound. This imparted to the immediate mound structure a halo-like effect of calcarenitic debris.

As noted previously, many of the larger McKelligon Canyon Formation organic buildups and, in particular, Lechuguilla Mound are cut by channels seldom more than 2 ft. in width, and which can reach a maximum measured depth of 12 ft. These channels are filled with dark-colored skeletal debris that contrasts sharply with the surrounding light-colored moundrock (fig. 5). It is thought that the channels were formed subaerially by solution and erosion, as outlined above. This sequence of events in the evolution of the El Paso mounds, diagramatically shown in Figure 22, probably took place continuously within the McKelligon Canyon Formation depositional interval and resulted in their formation. Evidence regarding this contention is as follows: (1) all boundaries of channel rock with moundrock are very sharp along smooth surfaces that cut through sponges, *Calathium, Pulchrilamina* colonies, and the mound matrix

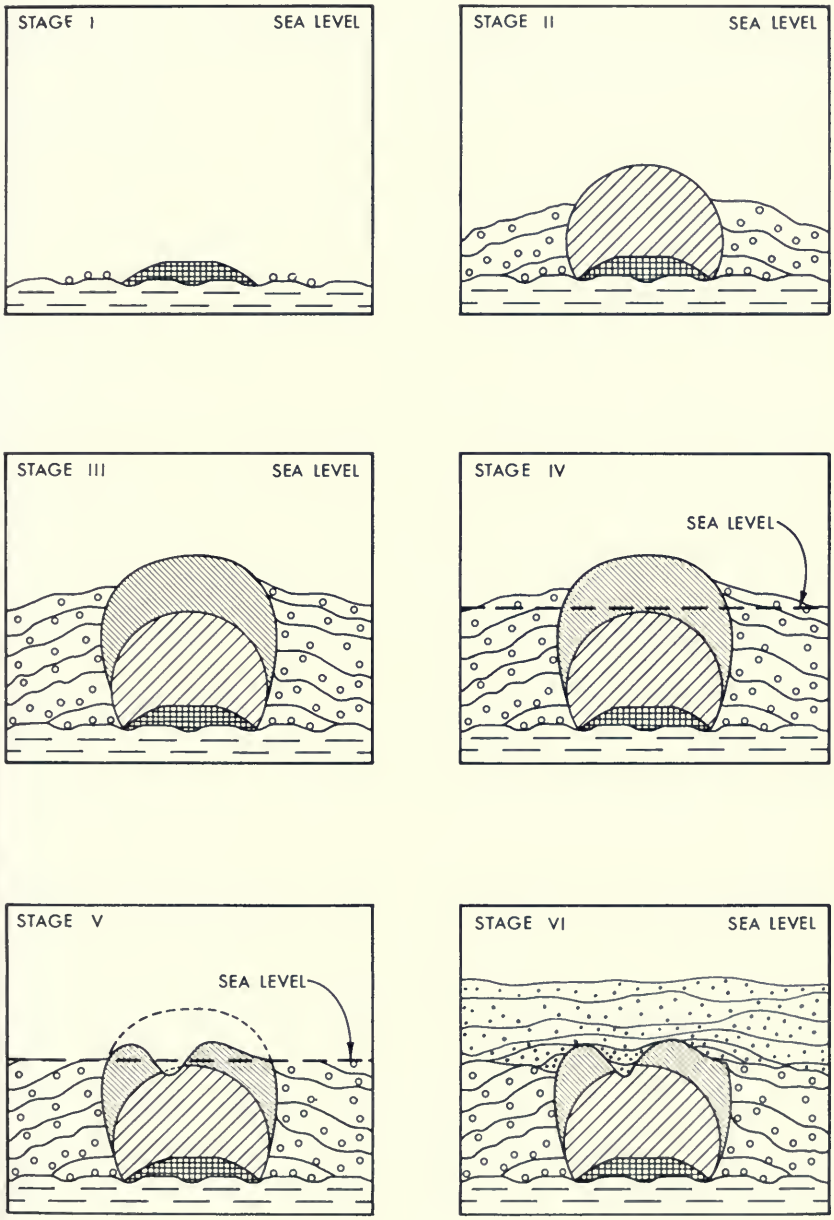



FIG. 22. Diagramatic sequence of growth stages and burial of typical McKelligon Formation organic buildup.

in a broad continuous sweep; it is believed that the mound matrix (mud) must have had some degree of consolidation; (2) on various mounds where the channels can be traced for any length, it is seen that they usually end in cul-de-sacs, and (3) if, as previously believed (Toomey & Klement, 1966; Toomey & Ham, 1967), these features represent surge channels that were present during the active growth of the organic buildup, they should be bordered by at least some entire colonies of constructional organisms. Further, the borders of the surge channels should be irregular rather than smooth. Hence we postulate that the channels are erosional and post-date lithification, since the channel-filling contains typical mound fossils, although broken and abraded. Because such channeled mounds occur at more than one level within the McKelligon Canyon Formation in the same area, it can be assumed that the entire process took place repeatedly during this interval.

**Summary.**—Organic buildups are prominent accretionary features in various horizons of the Lower Ordovician McKelligon Canyon Formation of the southern Franklin Mountains of West Texas, and in other mountain ranges of southern New Mexico. The organic buildups are numerous and well developed, contain a recognizable and distinctive biota, and possess characteristic petrological attributes.

One of the largest mounds discovered, Lechuguilla Mound, outcropping in the southern Franklin Mountains, was studied in detail in an attempt to understand the developmental history of this organic buildup. It was noted that this mound and some of the other larger mounds are cut by channels that are filled with coarse calcarenites. Study of the channels indicate that they are principally erosional features that were formed during repetitive stages, presumably when the organic buildups were subaerially exposed, eroded, and then subsequently filled-in with available debris. These erosional intervals appear to be intimately associated with shifts in sea level within an intertidal-to-subtidal depositional environment. Six stages in this overall process have been recognized and diagramatically shown in Figure 22. Study of all the data relating to the organic buildup biota suggests that at least three phases of organic development took place: (1) initiation of a pioneer colony, (2) evolvement of the pioneer colony into a more mature biotic community containing more varied and abundant biotic constituents, and (3) the development of a climax community characterized by the abundance and rise to dominance of the questionable coelenterate

*Pulchrilamina*, imparting to the organic buildup a distinctive framework capability. This biotic subdivision, so well displayed on the McKelligon Canyon Formation organic buildups, may simply refect organism response within increasingly shallower depositional environments.

## MONUMENT SPRING MEMBER OF THE MARATHON FORMATION, MARATHON REGION, SOUTHWESTERN TEXAS

**Stratigraphic History.**—The pioneer Texas geologist Robert T. Hill (1900) was the first to report the existence of pre-Carboniferous rocks in the Marathon region of southwestern Texas. He described a sequence of Paleozoic limestones, shales, and cherts that he regarded as of probable Devonian (Helderberg) age. Later, Johan August Udden (1907) examined the Marathon sequence on his way down into the Big Bend country along the Texas-Mexico border. Fossils were collected in the Marathon and these were passed on to Charles Schuchert for study and identification. Schuchert regarded them as Ordovician (Trenton) age.

It was not until 1915, when Baker & Bowman systematically collected fossils and engaged in stratigraphic reconnaissance that a viable stratigraphic succession was determined in the Marathon region. The results of their work was published in 1917, and included fossil determinations by E.O. Ulrich, who was able to differentiate six distinctive faunas in the collections. Baker & Bowman incorporated these findings and divided the Marathon succession into four formations, of which the Marathon "series" consisted of five members ranging in age from upper Ozarkian (Lower Ordovician) to lower Viola and lower Trenton (Upper Ordovician) of the New York sequence. Although their work created a beginning stratigraphic framework, they were discouraged by the complex structural relationships encountered in the area. Particularly, the folding and overthrusting added to the inherent difficulties of tracing beds and collecting fossils.

P.B. King in 1931 published the initial results of his work in the Marathon region based on field work done in 1929 and 1930. Detailed mapping by King and fossil collecting by Edwin Kirk, from 17 measured sections, indicated that rocks of Upper Cambrian, Lower, Middle, and Upper Ordovician, and probable Devonian ages were

present in the 2,500 ft. sequence of pre-Carboniferous rocks exposed in the Marathon Uplift.

Specifically, regarding the Lower Ordovician, King (pp. 1,066-1,069) upgraded the Baker-Bowman "Marathon series" by redefining the Lower Ordovician succession as the Marathon Limestone. He further subdivided this 500 to 1,000 ft. unit into three members: (1) a lower member of flaggy limestones, sandstones, and intraformational conglomerates separated by shale layers, (2) a massive dolomitic limestone near the middle of the formation and up to 75 ft. in thickness, that he named the Monument Spring Dolomite Member (p. 1,068), and (3) an upper unit identical in aspect to the lower member.

Significantly, Edwin Kirk noted that the Monument Spring Member "has a strong lithologic resemblance to the lower half of the El Paso limestone at El Paso." He added that the fauna from this middle unit contains plentiful algal masses *("Cryptozoon")*, sponges which include *Calathium,* orthoid brachiopods, poorly preserved gastropods, a single cystoid calyx (although he remarked that pelmatozoan ossicles occur in the rock in great numbers), and cephalopods *(Piloceras* and *Colpoceras*). According to Kirk, *(in* King, 1931, p. 1,069), "this fauna is nearly identical with that in the lower half of the El Paso limestone at El Paso, but particularly in the beds several hundred feet above its base."

This initial work of King was expanded into the classic 1937 monograph, in which he repeated (p. 26) an earlier statement regarding the Monument Spring Member, indicating that this competent unit:

> . . . is broken and shattered, so its outcrop is characteristically a chain of disconnected boulders. As a result of deformation the layer has been repeated in a most bewildering manner, and only careful field mapping does away with the impression that there are many beds of this sort in the section instead of one.

He also added that the maximum thickness is 94 ft., but that this thins to 25 ft. 8 miles toward the southwest.

Cloud & Barnes (1948, p. 65) mentioned that the Monument Spring Dolomite Member contains a molluscan-brachiopod fauna that normally characterizes Lower Ordovician rocks of the carbonate facies. However, the units above and below this member carry graptolites, which Reudemann had previously reported in King (1931, p. 1,070).

Recognizing that graptolite faunas did occur in relative abundance within the Marathon sequence, Berry (1960) carried out fieldwork in the area from 1954-1956 with the aim of subdividing the Ordovician succession so as to understand its relationship to the standard North American graptolite zonation. From this study, Berry was able to delineate 15 graptolite zones and correlate the Marathon succession with the well-known Ordovician graptolite-bearing rocks of Quebec and New York.

Berry (1960, p. 17) indicated that the Monument Spring Member lies completely within his zone 3, a faunal zone characterized by the graptolite *Tetragraptus approximatus* (Nicholson). He also stated that he collected other fossils from the Monument Spring Member (these included cephalopods *(Shumardoceras* and *Endoceras*) and the sponge *Archeoscyphia* [sic] aff. *A. annulatum* [sic] Cullison) and that sponge remains are relatively abundant in this member. Significantly, he (p. 19) compared sponges obtained from the Monument Spring Member with sponges he collected from the Kindblade Formation in the Arbuckle Mountains of southern Oklahoma, and concluded similar forms were present in both areas. He also mentioned that vague algal structures are apparent in this unit.

In an earlier work, Berry (1958, p. 392) stated that the Monument Spring Member occurs approximately 550 to 650 ft. above the base of the formation, and consists of oval lenses of dolomitic limestone aligned subparallel to each other and separated by shale and thin-bedded, cross-laminated limestone. These individual lenses range in size from 10 ft. long and 5 ft. wide to 50 ft. long and 25 ft. wide. The oval lenses contain the fauna mentioned above, and it was believed that these lenses were probably patch reefs constructed principally by algae and sponges and deposited in shallow water.

In the summer of 1960, the senior author spent three days in the Marathon region attempting to find these reported relationships. Instead, he found isolated, mound-shaped blocks of a blue-gray dolomitic limestone that look superficially very much like typical El Paso rock. Toomey (Toomey & Klement, 1966, p. 1,311) stated that he believed that the "patch reef hypothesis" was an over-simplification of the actual structural setting relative to the Monument Spring Dolomite Member.

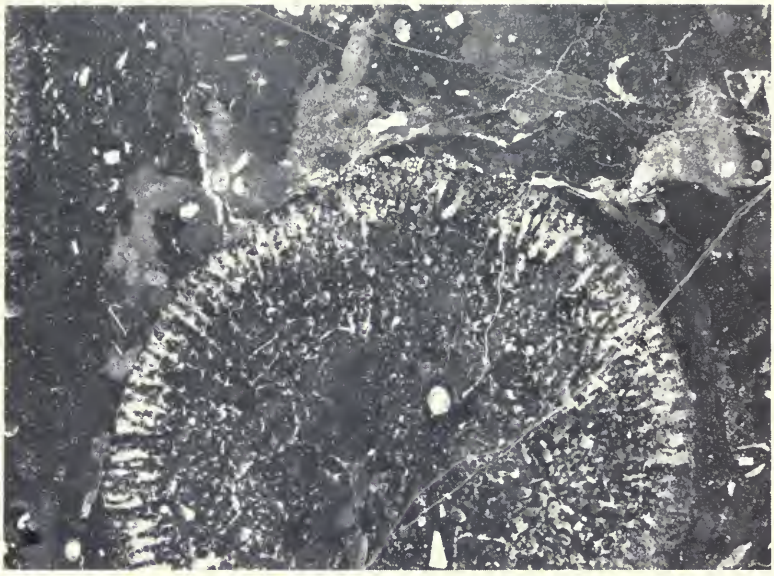
At this time, Earl McBride and his students from the University of Texas at Austin began a comprehensive study and re-evaluation of the sedimentary history of the Marathon Geosyncline. One

worker, Young (1969, 1970), found evidence in the Marathon Formation that specifically indicated early tectonic activity. This evidence of tectonism is recorded by the presence of three boulder beds, which he believed are olistostromes, that is, submarine landslides of great extent. The chief depositional mechanism was gravity displacement, which produced submarine turbidity currents, debris flows, and landslides. Young's primary contention was that this geosyncline was already a site of slope-controlled deposition and tectonic activity by at least Early Ordovician time.

Young (1970, pp. 2,306-2,307) considered the Monument Spring Dolomite Member a boulder bed, with the dominant boulder types mottled dolomite and dolomitic/silicified limestone. The maximum size of the blocks from this unit are 375 ft. in length and 45 ft. thick. Some of the large blocks are folded, and their geometry suggests that deformation developed before individual blocks were hardened. The interbedded shale beds are literally wrapped around some boulders. Many of the boulders are undoubtedly overturned, although diagnostic geopetal structures are uncommon. Of field importance is the observation that the boulder beds fill channels cut into the underlying strata.

Thus more recent evidence seems to suggest that the Monument Spring Dolomite Member was deposited by a single, large, tectonically induced submarine landslide that moved this allochthonous material from an active shelf margin into the subsiding geosycline. Young estimated (p. 2,313) "up to 21 cu km for the Monument Spring Dolomite Member alone." Based on consideration of the abundance of algal dolomite and dolomitic limestone boulders, the source of these boulders, and hence the origin of the Monument Spring Member, is thought to be west-northwest of the depositional basin and from a foreland subtidal-supratidal environment.

Hence, we see an evolving series of opinions that first regarded the Monument Spring Member as beds that were broken during folding and were locally rotated (King, 1937). Later, these blocks were interpreted to be mound-shaped patch reefs, built of algae and sponges (Berry, 1958, 1960). Berry, in fact, did not mention that these boulders were even folded, let alone contorted. Whereas Toomey (Toomey & Klement, 1966) thought that both these theories were structural over-simplifications, Young's theory that the Monument Spring Dolomite Member is one of three intraformational exotic boulder beds best seems to fit the available data.



a

b

**Subsequent Findings.**—In addition to new megafossil identifications, insoluble residues were prepared and a microfauna retrieved. A number of thin-sections were also prepared and further information obtained from this procedure.

**Petrology.**—Samples were collected from four large exotic blocks and a dozen thin-sections prepared and examined. Petrologically, the samples may be classified as slightly silty, burrowed, intraclastic skeletal wackestones. There are variations in the different types of skeletal grains present, but in most cases the dominant components are lithistid sponge fragments (fig. 23), and fragments of the problematical micro-organism *Nuia siberica* Maslov (Toomey & Klement, 1966, pl. 160, figs. 11, 12). The samples contain stromatolitic algal structures, and scattered dolomite rhombs are present throughout. Other skeletal grains include sponge spicules, echinoderm ossicles, orthoid brachiopod fragments, small turbinate-shaped gastropods (fig. 23b), and trilobite fragments. In general, skeletal grains do not occur in great abundances. Lithistid sponge fragments and sponge spicules, for instance, are nowhere near as common as they are in the McKelligon Canyon Formation at El Paso. Remains of *Nuia*, on the other hand, are relatively more abundant.

**Megafossils.**—Well-preserved megafossils are rare in the Monument Spring Member boulder beds and consist principally of sponges and cephalopods. One boulder in the Marathon Anticlinorium one-half mile north of Alsate Creek yielded a large fragment of an annulated sponge identified as *Archaeoscyphia annulata* Cullison. A number of poorly preserved, smaller lithistid sponges were also collected. These, too, show close affinities to *Archaeoscyphia*.

Of the cephalopods, only a few were collected from the boulders. These were identified by Unklesbay as *Rudolfoceras* sp., a form not previously reported from Texas or Oklahoma, but common in the Cassin Limestone of Vermont, an indeterminate longiconic

*Opposite:*

FIG. 23. Thin-section photomicrographs from the Lower Ordovician Monument Spring Member of the Marathon Limestone, exposed in the Marathon Anticlinorium, Brewster County, southwestern Texas. (a) Photomicrograph (×5) of a burrowed skeletal wackestone with a large lithistid sponge fragment (cf. *Archaeoscyphia*). (b) Photomicrograph (×8) of a burrowed skeletal wackestone. Note prominent turbinate-shaped gastropod in center of photo and sponge fragment in bottom right corner.

1
2
3
4
5
6
7
8
9
10
11
12
13

nautiloid, a *Tarphyceras* very close to *T. chadwickense* Ulrich, Foerste, Miller & Furnish, and an indeterminate form that is close to *Robsonoceras,* known from the Manitou Formation of Colorado.

**Conodonts.**—From formic acid residues of samples from seven Monument Spring exotic blocks a total of 350 identifiable conodonts were obtained. These were identified for us by Ethington, who recognized 29 different forms (table 2). Conodonts have previously been described from the shaly portions of the Marathon Formation by Graves & Ellison (1941). Some typical conodont species from the Monument Spring Member are shown in Figure 24. Most of the conodont elements in this collection are simple cones and all have rather long stratigraphic ranges. Ethington & Clark (1971) identified this faunal association as Fauna-D.

**Summary.**—No organic buildups *per se* have been identified from the Monument Spring Dolomite Member of the Marathon Formation. However, it has been shown that these beds are probably exotic blocks moved into the geosyncline by tectonic activity as submarine landslides from a shelf area west-northwest of the depositional basin. As had been recognized earlier (King, 1931; Kirk, 1934), these blocks are lithologically and faunally similar to the sponge-bearing horizons common in the McKelligon Canyon Formation exposed in the Franklin Mountains at El Paso. Provisional cor-

*Opposite:*

FIG. 24. Representative Lower Ordovician conodonts occuring in sponge beds of Texas and Oklahoma. (1) *Drepanodus arcuatus* Pander (× 66), oistodiform-element, Marathon Formation, Monument Spring Member, Marathon Anticlinorium. (2) *Drepanoistodus* sp. (× 86), oistodiform-element, Marathon Formation, Monument Spring Member, Marathon Anticlinorium.(3) *Scolopodus quadraplicatus* Branson & Mehl (× 53), Kindblade Formation, Joins Ranch section 100 ft. above base of formation.(4) aff. *Paltodus inconstans* Lindstrom (× 120), oistodiform-element, Kindblade Formation, Joins Ranch section 100 ft. above base of formation.(5) *Paroistodus* sp. (× 100), oistodiform-element, Marathon Formation, Monument Spring Member, Marathon Anticlinorium.(6) *Ulrichodina wisconsinensis* Furnish (× 86), Kindblade Formation, Highway 77 section 100 ft. above the base of the formation.(7) *Paltodus? sweeti* Serpagli (× 100). Marathon Formation, Monument Spring Member, Marathon Anticlinorium.(8) aff. *Scolopodus rex* Lindstrom (× 78) El Paso Group, McKelligon Canyon Formation mound horizon. (9) *Ulrichodina deflexa* Furnish (× 66), Kindblade Formation, Highway 77 section 100 ft. above the base of the formation. (10) New genus A (× 114), Cool Creek Formation, Highway 77 section *Archaeoscyphia* bed. (11) *Oneotodus simplex* (Furnish) (× 114), Cool Creek Formation, Highway 77 section *Archaeoscyphia* bed. (12-13) New genus and species. (12) Eobelodiniform-element (× 100), El Paso Group, McKelligon Canyon Formation mound horizon. (13) Prioniodiform-element (× 100), El Paso Group, McKelligon Canyon Formation mound horizon.

TABLE 2. Conodont assemblage from several exotic blocks of the Monument Spring Member of the Marathon Formation, Marathon Anticlinorium, Brewster County, southwestern Texas.

| SPECIES | NUMBER OF SPECIMENS |
|---|---|
| 1. *Acodus* aff. *A. deltatus* Lindstrom | |
| acodiform-element | 1 |
| distacodiform-element | 3 |
| triconodelliform-element | 12 |
| 2. *A. tetrahedron* Lindstrom | 8 |
| 3. *Drepanodus arcuatus* Pander | |
| arcuatiform-element | 11 |
| oistodiform-element | 13 |
| 4. Aff. "*D.*" *subarcuatus* Furnish | 20 |
| 5. *D. suberectus* (Branson & Mehl) | 11 |
| 6. drepanodiform-elements | 126 |
| 7. oistodiform-elements | 4 |
| 8. *Drepanoistodus* sp. | |
| oistodiform-element | 8 |
| 9. *D. forceps* (Lindstrom) | |
| oistodiform-element | 1 |
| 10. *Oneotodus simplex* (Furnish) | 5 |
| 11. ?*O.* sp. | 3 |
| 12. *Paltodus inconstans* Lindstrom | |
| drepanodiform-element | 1 |
| oistodiform-element | 5 |
| 13. "*P.*" *sweeti* Serpagli | 18 |
| 14. *Paroistodus* sp. | |
| oistodiform-element | 42 |
| 15. *Reutterodus* sp. | |
| multicostate-element | 1 |
| 16. Aff. *R. andinus* Serpagli | |
| bicostate-element | 1 |
| cone-element | 2 |
| multicostate-element | 2 |
| 17. "*Scandodus*" *americanus* Serpagli | 2 |
| 18. ?*S. brevibasis* (Sergeeva) *sensu* Serpagli | |
| acodiform-element | 3 |
| trichonodelliform-element | 1 |
| 19. Aff. *S. furnishi* Lindstrom | 2 |
| 20. Aff. "*S*" *robustus* Serpagli | 15 |
| 21. *S. toomeyi* (Ethington & Clark) | 10 |
| 22. *Scolopodus filosus* Ethington & Clark | 2 |
| 23. *S. gracilis* Ethington & Clark | 3 |
| 24. *S. quadraplicatus* Branson & Mehl | 1 |
| 25. Aff. *S. rex* Lindstom | 6 |
| 26. *S. triangularis* Ethington & Clark | 1 |
| 27. *S. triplicatus* Ethington & Clark | 2 |
| 28. *Ulrichodina abnormalis* (Branson & Mehl) | 1 |
| 29. *Walliserodus comptus* (Branson & Mehl) | |
| quadricostate-element | 3 |
| Total number of specimens | 350 |

relation of the Monument Spring Member with faunally similar beds in the El Paso and Ellenburger Groups is shown in Figure 1.

The reported occurrences of the alga *Calathium* in the Monument Spring Member was originally based on the identification by King (1931, p. 27), and is attributed to Kirk. Dake & Bridge (1932, pl. 12, fig. 15) illustrated a large silicified sponge from the upper Ellenburger (Honeycut Limestone) which they identified as *Calathium* sp. They remarked (p. 741) that sponges of similar types are also found in the Monument Spring Member of the Marathon region. Unfortunately, this is a mis-identification, and the Dake & Bridge specimen is a bona fide *Archaeoscyphia*, as already recognized by Kirk (1934, p. 457). No true *Calathium* are known from the Monument Spring Member of the Marathon Formation.

## ELLENBURGER SPONGE BEDS OF CENTRAL TEXAS

**Stratigraphic Relationships.**—The "Ellenburger Limestone" of early workers, especially Paige, 1911 and 1912, was nomenclaturally revised to group status by Cloud et al. in 1943. As so defined, the Ellenburger Group is restricted to rocks of Lower Ordovician age. The Ellenburger Group, as exposed in the Llano region of central Texas, is divided into three formations. From oldest to youngest these formations are the Tanyard Formation (comprising the Threadgill and Staendebach Members), the Gorman Formation, and the Honeycut Formation. For all practical purposes, these three Ellenburger formations are essentially equivalent to earlier named, and perhaps better known, stratigraphic units exposed in the Ozark Uplift of Missouri. Cloud et al. felt that new names were needed for the Llano region of the central Texas primarily because of basic lithological differences and geographic isolation (see relationships shown in Figure 3).

Known outcrops of the Ellenburger Group are exposed in the Llano Uplift of central Texas. Within this area Ellenburger rocks occur either at the margins of the basin-like structural uplift or in the block-faulted outliers of Paleozoic rocks that may be entirely surrounded by Precambrian rocks (Cloud & Barnes, 1948, pp. 31-32). Maximum known thickness of Ellenburger rocks (approximately 1,820 ft.) occurs in the southwestern part of the Llano Uplift in the vicinity of Johnson City, Blanco County, Texas. Westward and northward from this area the Ellenburger Group thins, mainly by truncation of the upper beds (Honeycut and Gorman Formations), but also, in part, by westward thinning of the Tanyard Formation. Effective truncation of the Ellenburger Group is believed to have been a pre-Devonian event, although Ellenburger strata were subsequently overlapped at other times by younger sediments. This post-Ellenburger truncation has completely removed the Honeycut Formation west of the western half of San Saba County, and this is best shown in the northwestern part of the Llano region (fig. 25).

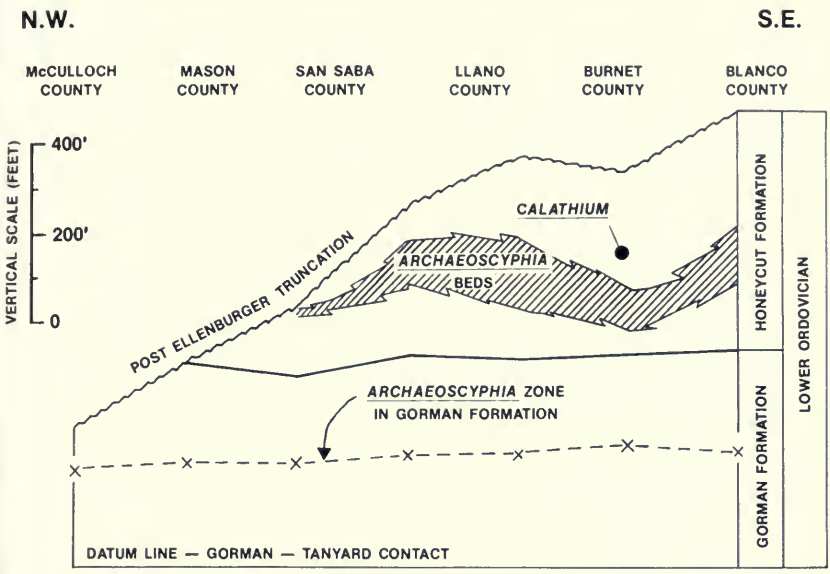



FIG. 25. Stratigraphic distribution of *Archaeoscyphia* in the middle and upper Ellenburger Group of central Texas (from Toomey, 1964).

The Ellenburger Group is separated by a profound erosional unconformity from the various post-Lower Ordovician strata that rest upon it (Devonian, Mississippian, Pennsylvanian, and Cretaceous). Contact of the basal Ellenburger with the underlying Cambrian rocks is inconspicuously disconformable or apparently conformable. At most places in the outcrop region, the contact between the Tanyard and Gorman Formations also appears to be conformable. The contact between the Gorman and overlying Honeycut Formations is uniformly even, and also appears to be conformable. Significantly, Cloud & Barnes (1948, p. 35) noted that interruption in sedimentation at this contact is suggested by sand-filled burrows present on the upper surface of the Gorman Formation in the Gorman Falls area of southeastern San Saba County. In addition, changes in environmental conditions are apparent by changes in rock lithology and faunal content. In fact, the faunal break at the Gorman-Honeycut formational boundary is more pronounced and abrupt than in any of the other formations, and is perhaps the most significant.

**Lithology.**—Most of the limestones of the Ellenburger Group are muddy carbonates of fine texture, varying in color from grays to

browns. Some limestones are distinctly stromatolitic, and intraformational conglomerates and breccias occur. Some pelletoidal carbonates also occur, but many of the rocks described as pelletoidal, at least in the Honeycut Formation, are indeed more accurately described as intraclastic-skeletal packstones.

The occurrence of stromatolites in many of the Ellenburger units indicates an algal origin for these rocks, and suggests shallow water depositional environments ranging from subtidal to supratidal conditions. Shallow water deposition is also suggested by the occurrence of ripple marks and intraformational conglomerates and breccias. The definite pelletoidal limestones, which occur locally throughout the entire Ellenburger sequence, strongly suggest the activity of mud-ingesting benthonic organisms.

Ellenburger dolomites run the gamut from fine-grained to coarse-grained, with the more vividly colored dolomites (reds, yellows, and browns) occurring largely in the Gorman Formation, and to a lesser degree in the Honeycut Formation. These dolomites show greater lateral persistence than the generally lighter-colored and coarse-grained dolomites of the basal Tanyard Formation.

No organic buildups *per se* have been found in any of the Ellenburger formations, although many biostromal units, especially in the Honeycut Formation, contain well-preserved algal-sponge remains.

**Algal-Sponge Biostromal Units.**—Persistent, though thin, biostromal units containing an algal-sponge biota occur in both the Gorman and Honeycut Formations of the Ellenburger Group.

Sparse remains of the lithistid sponge *Archaeoscyphia* occur in a relatively thin stratigraphic interval approximately in the middle of the Gorman Formation (fig. 25), and can be accurately delineated across the entire Llano Uplift. In contrast, abundant specimens of *Archaeoscyphia annulata* Cullison are found in many thin stratigraphic horizons within the lower one-third of the Honeycut Formation. The sponges, associated with algae and other organisms, occur in biostromal units composed of chert-bearing intraclastic limestones. The large alga *Calathium* has only been found in one area of the Llano Uplift (Burnet County) (fig. 25). Apparently, in a northern and western direction across the uplift the *Calathium*-bearing interval has been erosionally truncated, coincident with the general Honeycut Formation truncation in this direction.

The first reported occurrence of an algal-sponge fauna from the

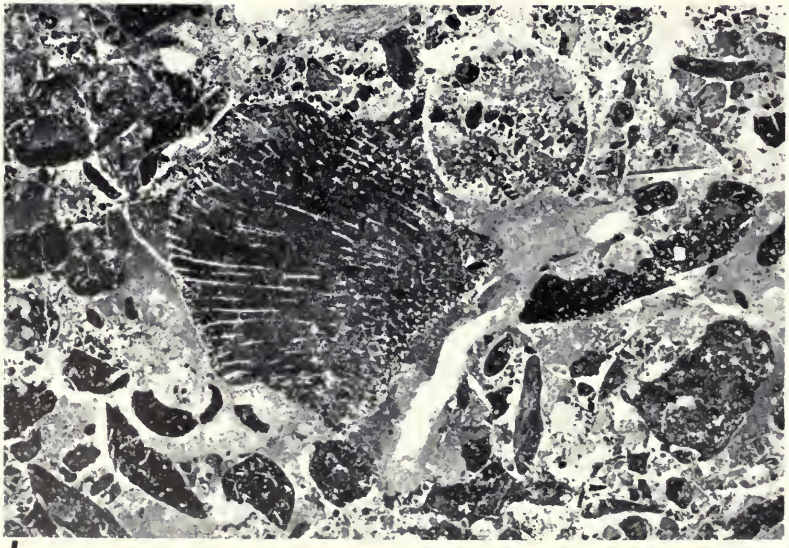
Ellenburger was made by Dake & Bridge (1932, p. 738) when they reported "*Calathium*" as being the principal fossil in a zone of Honeycut rocks near Marble Falls, in southwestern Burnet County. In the same publication, they illustrated a "*Calathium*" (pl. 12, fig. 15) which they had collected from the Honeycut Formation of Llano County. The illustrated specimen was misidentified; it is an undoubted *Archaeoscyphia.*

The preliminary progress report on the Ellenburger Group by Cloud et al. (1943) and the excellent monograph by Cloud & Barnes (1948) fully documented the stratigraphic relationships and occurrences of Gorman and Honeycut algal-sponge biostromal units, and served as the basic framework for this investigation. Later, Barnes et. al (1959) presented a comprehensive review of all subsurface occurrences of Ellenburger fossils. In this report the lithistid sponge *Archaeoscyphia* was identified in well samples and cores from the Honeycut Formation in Collin, Crockett, Kendal, Schleicher, Gray, and Upton counties, west of the Llano Uplift outcrop area.

As noted above, specimens of the lithistid sponge *Archaeoscyphia annulata* Cullison occur persistently, although not abundantly, in a thin stratigraphic interval located near the middle of the Gorman Formation. The stratigraphic position of this *Archaeoscyphia* horizon ranges from 210 to 262 ft. above the base of the Gorman, and from 201 to 235 ft. below the top of the formation. In most occurrences *Archaeoscyphia* ranges through only 3-5 ft. of Gorman strata, but locally, as in some outcrops in Mason County, its stratigraphic range may be as much as 25 ft. above the main bed of occurrence. This sponge horizon occurs throughout all of the Llano Uplift area, and is used as an important faunal datum in surface mapping (fig. 25). The Gorman *Archaeoscyphia* zone has not been identified in the Ellenburger subsurface.

In all observed occurrences, Gorman *Archaeoscyphia* consists principally of circular cherty fragments and chert nodules, usually rust or orange colored, scattered along the outcrop surface. Its detection as a sponge is demonstrated by the lithistid spicular meshwork of the sponge wall, which can be readily observed on a freshly broken rock surface, especially with the aid of a handlens. No whole specimens of *Archaeoscyphia* have been found from this zone, although enough fragments have been collected to show the characteristic annular sponge wall. Lithologically, the Gorman Formation is predominantly dolomitic below the zone of *Archaeoscyphia* and calcitic above.

a



b

The Gorman *Archaeoscyphia*-bearing rock can be described petrologically as an intraclastic-pelletoidal skeletal wackestone-packstone. Locally, the rock may even be oolitic. Associated fossils, although meager, include the brachiopod *Syntrophinella* sp., the gastropod *Rhombella* sp. cf. *R. umbilicata* Ulrich & Bridge, and other indeterminate gastropods and cephalopods. Cloud & Barnes (1948, p. 116) report a large *Clitendoceras*-like cephalopod from this zone in the Cherokee area, southeastern San Saba County.

In contrast to the Gorman *Archaeoscyphia* zone, abundant *Archaeoscyphia* associated with a diverse biota are found in a number of relatively thin limestone units exposed within the lower one-third of the Honeycut Formation. Two Honeycut sponge-bearing beds have been examined and collected. The principal bed occurs at the Rough Hollow section in the Honeycut Bend area of Blanco County. This bed is 5 ft. thick and is Cloud & Barnes' (1948) unit 100. The other bed is a 4 ft. thick sponge-bearing horizon referred to as the Burke Ranch locality, also in Blanco County. Both these locations are well shown on the map on Plate 3 of Cloud & Barnes (1948). The sponge-bearing interval occurs from 50 to 150 ft. above the base of the formation. The actual zone of sponge occurrences ranges from 37 to 160 ft. in thickness. The thin 37 ft. interval occurs in southcentral San Saba County, where the greater portion of the *Archaeoscyphia* beds, and indeed most of the Honeycut Formation, have been removed by post-Ellenburger truncation.

The Honeycut sponge beds are skeletal limestones and dolomitic limestones intercalated with non-fossiliferous limestones and dolomites. Most of the *Archaeoscyphia* are found in the non-dolomitic limestones. Petrologically, the sponge-bearing beds can be classified as intraclastic-pelletoidal skeletal wackestones (fig. 26). The outcrop surfaces of these beds usually contain abundant rust-colored chert nodules and distinctive chert "cannonballs." Some of the chert "cannonballs" have a diameter of slightly more than 1 ft. Most of the obvious sponge material present in the Honeycut beds

---

*Opposite:*

FIG. 26. Thin-section photomicrographs (×3½) from the Ellenburger Honeycut Formation in central Texas. (a) Sponge-bearing skeletal wackestone from the main *Archaeoscyphia* bed at the Rough Hollow section, Blanco County, Texas; note the transverse section of the lithistid sponge *Archaeoscyphia* in upper-half of photo and cephalopod fragment in lower-half. (b) Intraclastic-skeletal packstone from the upper bed at the Burke Ranch section, Blanco County, Texas; note the lithistid sponge spicule intraclast in center of photo (from Toomey, 1964).

are associated with the chert nodules and "cannonballs." The chertified Honeycut sponges preserve enough of their characteristic external morphology and spicular meshwork so that they may be identified as *Archaeoscyphia annulata* Cullison. However, even though *Archaeoscyphia* are abundant in many of the lower Honeycut beds, most specimens seen and collected for this study appear as incomplete broken specimens that are scattered along the bedding plane surfaces (fig. 27b). We have found no sponges in what would be regarded as original growth position, and no clusters of sponges or root systems have been found. The size of *Archaeoscyphia* ranges from relatively small forms a little over 1 in. in length, to one giant *Archaeoscyphia* that measured 15 in. in length with a diameter of 3½ in. Most *Archaeoscyphia* average 5 to 6 in. in length, with a diameter of up to 2 in. Typical silicified *Archaeoscyphia* retrieved from acid etching are shown on Figure 28, along with representative lithistid spicules.

Slabbing of much of the sponge-bearing rock has also brought to light many calcified specimens of *Archaeoscyphia* (fig. 26a).

Associated with *Archaeoscyphia* is an abundant and diverse biota consisting of the blue-green alga *Girvanella* (fig. 27c), pelmatozoan fragments; the orthid brachiopods *Finkelnburgia* sp. cf. *F. cullisonia* Ulrich & Cooper and *Xenelasma synthrophioides* Ulrich & Cooper; the gastropods *Orospira* sp., *Hormotoma* sp., *Eopteria* sp. aff. *E. etna* (Billings), and *Barnesella lecanospiroides* Bridge & Cloud; the diagnostic gastropod opercula *Ceratopea capuliformis* Oder and *C. incurvata* Yochelson & Bridge; cephalopod siphuncles, mainly mcqueenoceroid-types; the coiled nautiloid *Tarphyceras chadwickense* Ulrich, Foerste, Miller & Furnish; the trilobites "*Jeffersonia*" *granosa* (Cullison), *Strigigenalis* sp., and *Pseudohystricurus* sp.; and varied distacodid conodonts (table 3).

Much of the skeletal material seen in thin-sections from this horizon appears to be associated with swirls of algal laminae and *Girvanella* threads. Figure 29 is a schematic reconstruction of the Rough Hollow sponge-bearing biostromal unit.

The alga *Calathium* has only been found at one locality in the Llano Uplift. It occurs in Cloud & Barnes (1948, p. 295) unit 29 of the Honeycut Formation at the Roaring Springs section, southwestern Burnet County. This location is shown on Figure 25. The *Calathium*-bearing unit is 4 ft. thick, and is approximately 240 ft. above the base of the Honeycut Formation. Relatively few specimens of *Calathium* have been collected from this locality. All

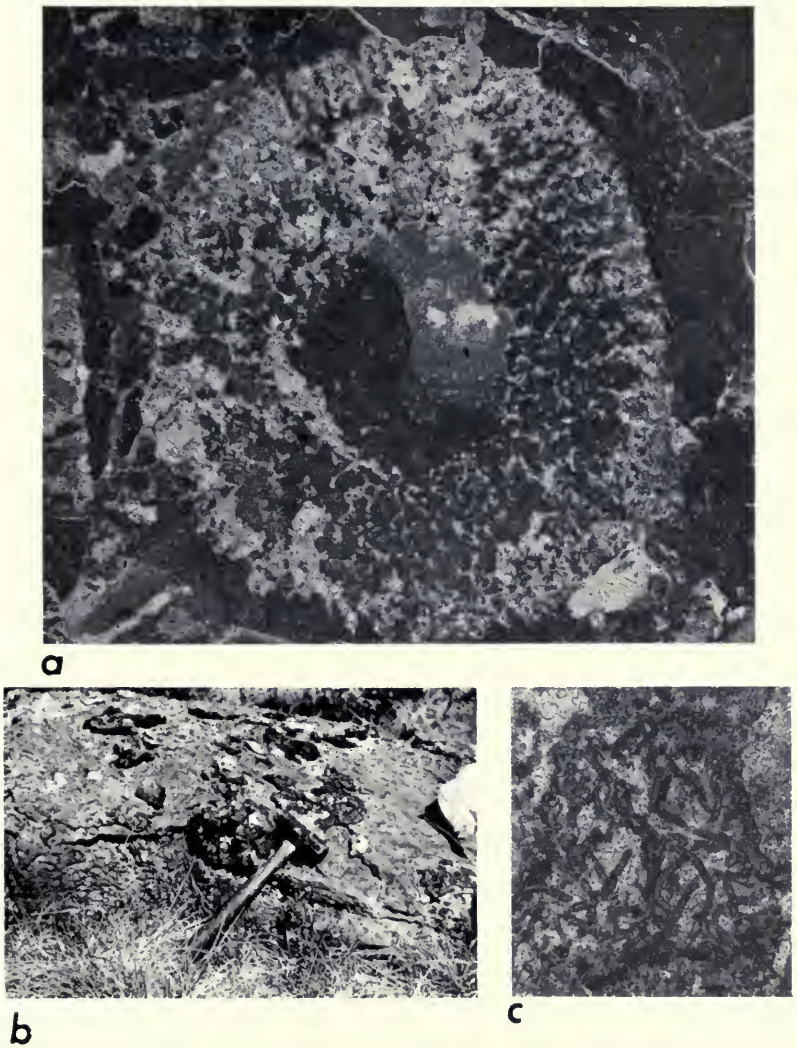



FIG. 27. Photographs from the main sponge-bearing horizon present in the Ellenburger Honeycut section at Rough Hollow, Blanco County, Texas. **(a)** Thin-section photomicrograph ( × 8) of a transverse cut through an *Archaeoscyphia* sponge: **(b)** Outcrop photograph showing abundant chert replaced *Archaeoscyphia* on the outcrop surface, length of hammer is 15 in. **(c)** Thin-section photomicrograph ( × 55) of tubules of the blue-green alga *Girvanella* commonly present in this horizon (in part from Toomey, 1964).

TABLE 3. Conodont assemblages from the Lower Ordovician (Kindblade-Honeycut) horizons of abundant *Archaeoscyphia* in southern Oklahoma and central Texas.

| Conodont Identifications | Arbuckle Group Kindblade Formation | | | | | | | Ellenburger Group Honeycut Formation | |
|---|---|---|---|---|---|---|---|---|---|
| | Arbuckle Mountains | | | | Wichita Mountains | | | Llano Region, Central Texas | |
| | Joins Ranch | Highway 77 | Southern Tishomingo Anticline | Mill Creek | Kindblade Ranch | Unap Mountain | Longhorn Mountain | Rough Hollow | Total number of specimens |
| 1. Aff. *Acodus tetrahedron* Lindström | 4 | - | - | - | 1 | - | - | - | 5 |
| 2. *Drepanodus arcuatus* Pander arcuati-form-element | 6 | - | - | - | 1 | 1 | - | - | 8 |
| 3. "*D.*" *subarcuatus* Furnish | 82 | 50 | 13 | 46 | 28 | 10 | 23 | 24 | 276 |
| 4. "*D.*" *suberectus* (Branson & Mehl) | - | 4 | - | - | 1 | - | - | - | 5 |
| 5. drepanodiform-elements | 43 | 24 | 6 | 29 | 15 | 1 | 13 | - | 131 |
| 6. *Drepanoistodus* aff. *D. forceps* (Lindström) oistodiform-element | 1 | - | - | - | - | - | - | - | 1 |
| subrectiform-element | 2 | - | - | - | - | - | - | - | 2 |
| 7. *Oneotodus* aff. *O. nakamurai* Nogami | - | 34 | - | - | - | - | - | - | 34 |
| 8. *O. simplex* (Furnish) | 34 | 24 | 2 | 9 | 3 | 1 | 1 | - | 74 |
| 9. *O. variabilis* Lindström | 2 | - | - | - | - | - | - | - | 2 |
| 10. Aff. *Palodus inconstans* Lindström oistodiform-element | 42 | 11 | 4 | 9 | 6 | 1 | 14 | - | 87 |
| 11. Aff. "*P.*"*? sweeti* Serpagli | - | 1 | - | - | - | - | - | - | 1 |
| 12. paltodiform-elements | - | 7 | - | - | - | - | - | - | 7 |
| 13. *?Juanognathodus* sp. | - | - | - | 1 | - | - | - | - | 1 |
| 14. *Scandodus toomeyi* (Ethington & Clark) | - | - | - | 2 | - | - | - | - | 2 |
| 15. Aff. "*S.*" *robustus* Serpagli | - | - | - | - | - | 1 | - | - | 1 |
| 16. scandodiform-elements | 3 | - | - | - | 1 | 1 | - | 10 | 15 |

| Conodont Identifications | Arbuckle Group Kindblade Formation | | | | | | | Ellenburger Group Honeycut Formation | |
|---|---|---|---|---|---|---|---|---|---|
| | Arbuckle Mountains | | | | Wichita Mountains | | | Llano Region, Central Texas | |
| | Joins Ranch | Highway 77 | Southern Tishomingo Anticline | Mill Creek | Kindblade Ranch | Unap Mountain | Longhorn Mountain | Rough Hollow | Total number of specimens |
| 17. *Scolopodus filosus* Ethington & Clark | 3 | 2 | - | 4 | - | - | - | - | 9 |
| 18. *S. gracilis* Ethington & Clark | 7 | 6 | 2 | 10 | 21 | - | 7 | 24 | 77 |
| 19. *S. iowensis* (Furnish) | 6 | - | - | 6 | 2 | - | - | - | 14 |
| 20. *S. propinquus* (Furnish) | 3 | - | 1 | - | - | - | - | - | 4 |
| 21. *S. quadraplicatus* Branson & Mehl | 120 | 38 | 12 | 53 | 25 | 10 | 2 | 72 | 332 |
| 22. *S. staufferi* (Furnish) | 4 | 5 | 2 | 8 | 3 | 2 | - | 6 | 30 |
| 23. *S. triangularis* Ethington & Clark | 32 | 32 | 8 | 16 | 11 | 2 | 8 | - | 109 |
| 24. *S. triplicatus* Ethington & Clark | 89 | 53 | 10 | 39 | 32 | 6 | 24 | - | 253 |
| 25. Scolopodiform-elements | 2 | - | - | - | - | - | - | - | 2 |
| 26. *Ulrichodina abnormalis* (Branson & Mehl) | 2 | 1 | - | - | - | - | - | - | 3 |
| 27. *U. deflexa* Furnish | 10 | 7 | 1 | 5 | 32 | - | 4 | 3 | 62 |
| 28. *U. wisconsinensis* Furnish | 3 | 2 | - | - | - | 2 | - | - | 7 |
| 29. *Walliserodus comptus* (Branson & Mehl) quadricostate-element | - | - | - | 1 | - | - | - | - | 1 |
| 30. New genus A [= *Panderodus compressus* (Branson & Mehl) *sensu* Mound, 1968] | - | 7 | - | - | - | - | - | - | 7 |
| 31. New genus B [aff. "*Scolopodus*" *peselephantis* Lindström] | - | 5 | - | - | - | - | - | - | 5 |
| TOTAL | 500 | 313 | 61 | 238 | 182 | 38 | 96 | 139 | 1,567 |

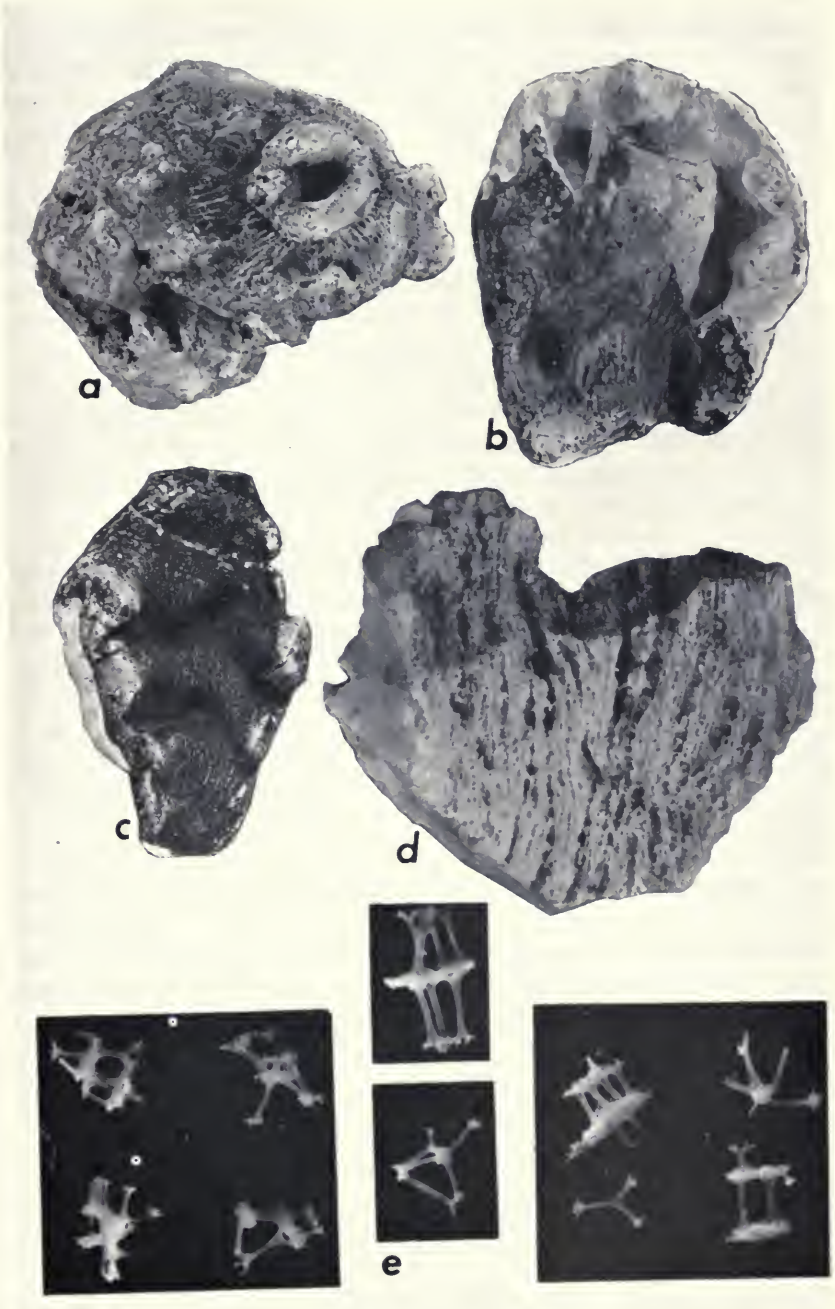
come from a single bed of skeletal wackestone containing large chert "cannonballs." Fossils obtained from the "cannonballs" are poorly preserved specimens of the gastropod *Orospira* sp. and the trilobite "*Jeffersonia*" sp. A thin-section from this horizon also shows the presence of the problematical micro-organism *Renalcis* sp.

**Paleoecologic Setting of the Ellenburger Sponge Beds.**—Cloud & Barnes (1957, p. 164) presented a synopsis of the lithologic and paleontologic attributes of these beds and suggested that the Ellenburger sediments were laid down in a relatively shallow water depositional environment. They even suggested that some of the stromatolitic beds, mainly present in the Gorman and Honeycut Formations, may have actually had their optimimum development on broad tidal flats, or even higher, on the periodically flooded supratidal flats. They further suggested that the Ellenburger Sea was warm, and that tropical or subtropical conditions prevailed as indicated by the great succession of chemically precipitated carbonates. Significantly, they also noted that the Ellenburger biota, on the basis of numbers of species and variety alone, is not at all comparable with warm water biotas of the present seas, except those found in geographic areas possessing unusual environmental requirements. One such area is the present day Bahama Bank, Bahamas. Accordingly, the present Bahama Bank was accepted as a type model to which analogy and comparison could be made lithologically, faunally, and ecologically.

In regard to the distribution of fossil organisms within the Ellenburger, Cloud & Barnes noted that organism patterns are patchy and occurrences intermittent. This would suggest a generally soft bottom substrate, which could inhibit prolific development of a shelly benthos. Nonetheless, there undoubtedly existed favorable oases or local areas where a shelly benthonic fauna could thrive, and even survive through ecologically unfavorable periods. That this indeed actually happened during Ellenburger time appears to be reflected in the very patchy fossil distribution patterns reported by Cloud &

*Opposite:*

FIG. 28. Acid-etched specimens of the sponge *Archaeoscyphia annulata* Cullison from the main Ellenburger Honeycut sponge-bearing horizon at Rough Hollow, Blanco County, central Texas. (a-c) Examples of typical chertified specimens (½ natural size). (d) Close-up photo (× 3) showing the spicular meshwork. (e) Series of various lithistid spicules (× 20), mainly desmas—irregularly shaped spicules that form the skeletal meshwork of *Archaeoscyphia;* spicules can be classified as monocrepids and tetracrepids (in part from Toomey, 1964).


a
b
c
d
e

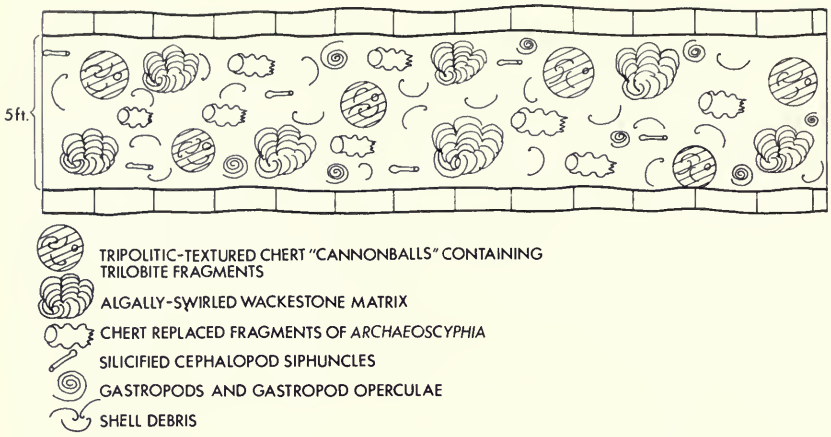



FIG. 29. Schematic diagram of an algal-sponge-bearing biostromal unit in the Honeycut Formation of central Texas.

Barnes. Although the remains of shell-bearing organisms are comparatively rare in much of the Ellenburger sequence, the abundance of units containing pelletoidal carbonates strongly suggests the continued presence, throughout much of Ellenburger time, of an abundant, probably soft-bodied, mud-ingesting biota.

As to the significance of the Ellenburger sponge faunas, especially in the Gorman and Honeycut intervals, we have previously noted that none of the *Archaeoscyphia* can be regarded to be in growth position, and most, if not all collected specimens, appear to be randomly strewn across the outcrop surface. This would tend to suggest that the sponges are not indigenous to the rocks in which they are found. Most probably, the sponges have been derived from relatively shallow offshore waters, and later were deposited within shallow intertidal waters. Field (1931, p. 773) noted an analogous situation in his study of the present day Bahama Bank where:

> "Farther from shore, in only slightly deeper water, a few other forms appear, chitinous sponges, hydroids, crustaceans, and calcareous algae become more prominent. Here a much greater degree of bottom permanence exists, although disturbance of the fine-grained calcareous sediment occurs rather frequently, caused by wave action and bottom "stirup." The sponge colonies and associated fauna occur in places where the hard rock bottom appears near the upper surface of the calcareous mud. The sponge colonies tend to change their position from year to year, and especially after long and severe storms."

In a later study of the Bahama Bank, Smith (1940, p. 150) noted that: "many sponges break off from their original attachment and

become 'rollers' when they occur wherever the currents drift them." The wide distribution of Ellenburger *Archaeoscyphia*, can, perhaps, also be explained in relationship to this analogy. In essence, we may postulate that at various Gorman and Honeycut times colonies of *Archaeoscyphia* grew in relatively shallow, subtidal offshore waters. They lived in scattered patches where ecological conditions were favorable, and especially where a firm substrate was available. During times when wave and current action became vigorous, some sponges were undoubtedly ripped-up from the substrate and scattered. These loose sponges would be at the mercy of the currents and eventually be driven into shallower intertidal waters. Here they were probably further wave battered, but eventually they were incorporated into these sediments. We would not think that sponges as large and massive as *Archaeoscyphia* could be indigenous within the very shallow intertidal and periodically subaerially exposed supratidal environment. It is difficult to imagine *Archaeoscyphia* as indigenous forms in such an ecologically harsh stress environment with pronounced salinity fluctuations, marked tidal oscillations, substrate instability, and ultimate subaerial exposure.

It is of interest to note that *Archaeoscyphia* "rollers" and abundant chert "cannonballs" are rather common associates, particularly within the Honeycut Formation. It may be that there is some relationship, as yet unexplained, between the formation and occurrence of "cannonball" cherts and the role of the siliceous sponge as a nucleus or triggering agent for chert accretion.

## SPONGE HORIZONS AND ORGANIC BUILDUPS IN THE LOWER ORDOVICIAN OF OKLAHOMA

As in the Texas locations, sponge horizons and organic buildups are relatively common in distinctive stratigraphic intervals within the Lower Ordovician sequence. They occur in both the Wichita and Arbuckle Mountains of southwestern and southern Oklahoma. The organic buildups are primarily of algal-sponge composition and are relatively small-scaled sedimentary structures. Their stratigraphic position and relationship to coeval horizons in Texas, discussed above, is shown in Figure 1. Also, see Figure 2 showing the postulated paleogeographic setting for this region during Lower Ordovician time.

For this study three outcrop localities in the Wichita Mountains of far southwestern Oklahoma and four outcrop localities in the Arbuckle Mountains of southern Oklahoma were collected and studied in detail (fig. 30).

In the Kindblade Formation of the Arbuckle Group, exposed in southern Oklahoma, organic buildups are relatively common in two 50-ft. stratigraphic horizons present above the base of the formation (fig. 31).

The lower mound horizon is located approximately 50-100 ft. above the base of the Kindblade Formation. This interval is characterized by relatively small organic buildups, seldom attaining a mound size greater than 5 ft. in height. The mounds contain abundant clusters of the lithistid sponge *Archaeoscyphia annulata* Cullison. The receptaculitid alga *Calathium* is of secondary importance, and the laminated encrusting organism *Pulchrilamina spinosa* Toomey & Ham occurs only rarely. Petrologically, the moundrock can be described as a skeletal wackestone with intervals of abundant stromatolitic algae. In some instances, skeletal material is bound up within the stromatolitic layers. This mound horizon is well developed in the Arbuckle Mountains, especially in the

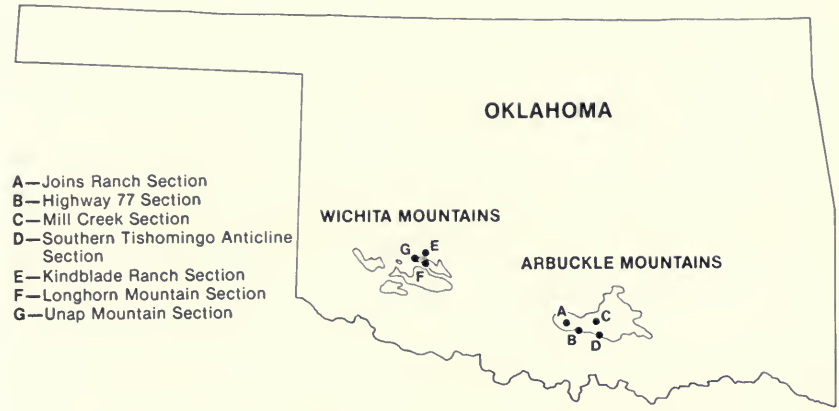



FIG. 30. Location map showing Lower Ordovician Kindblade sections in the Wichita and Arbuckle Mountains of southern Oklahoma (modified from Rigby and Toomey, 1978).

Highway 77 section, but is not so well exposed in the Wichita Mountains, 90 miles to the west. Here, the best exposure of this lower *Archaeoscyphia*-dominated mound horizon occurs at the Kindblade Ranch location.

The upper mound horizon occurs within a stratigraphic interval 450-500 ft. above the base of the Kindblade Formation. This horizon is well exposed in both ranges, and is characterized by massive organic buildups. Maximum mound development in the Wichita Mountains occurs in the Longhorn Mountain section, where the largest mound is 65 ft. high and 175 ft. in length. The largest observed organic buildup exposed in the Arbuckle Mountains is approximately 13 ft. high, and about 50 ft. in length. These massive organic buildups are dominated by abundant clusters of the receptaculitid alga *Calathium,* associated with common *Archaeoscyphia.* Much of this algal-sponge material is bound up by stromatolitic algae and by problematical algal (?) forms such as *Epiphyton* and *Renalcis.* The encrusting laminated form *Pulchrilamina spinosa* Toomey & Ham is relatively common throughout most of the better developed organic buildups. Petrologically, much of the moundrock can be described as an organic boundstone, especially where there is an interplay of stromatolitic algae associated with algally bound sponges and large receptaculitid algae. Accessory organisms are relatively common and consist of orthid brachiopods, various gastropods, coiled and straight cephalopods, chiton plates, trilobites, ceramoporid bryozoans, and conodonts. Associated with

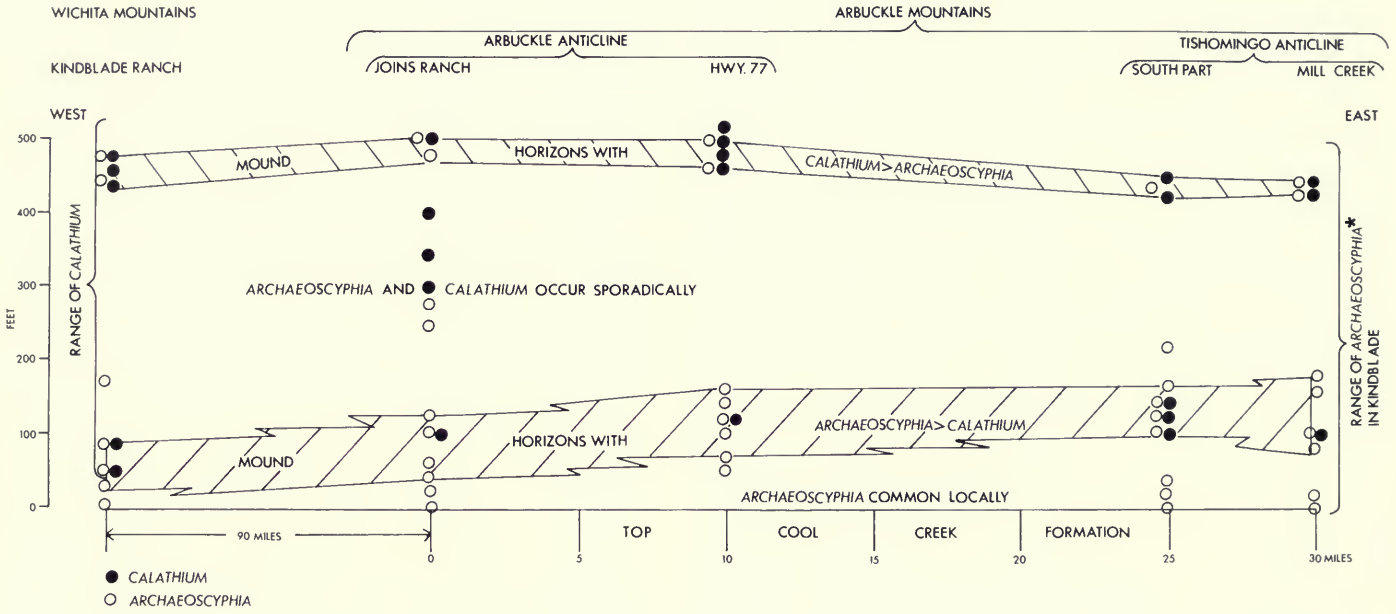



FIG. 31. Stratigraphic and geographic distribution of *Archaeoscyphia* and *Calathium* in lower part of Kindblade Formation, Wichita and Arbuckle Mountains, southern Oklahoma (modified from Rigby & Toomey, 1978).

**Archaeoscyphia* also occurs in a distinct zone approximately 770 ft. below the top of the Cook Creek Formation in the Arbuckle Mountains. This horizon was searched for, but not found in the Wichita Mountains.

these organic buildups are anastomosing channels, probably of erosional origin, and filled with coarse, sorted packstones and grainstones. Most allochem material in the channel is intraclasts, although fragmented skeletal grains, derived from the adjacent mounds, are also conspicuous. Channels associated with the organic buildups in southern Oklahoma are not nearly as well developed as those described above from the McKelligon Canyon Formation of West Texas.

As shown in Figure 31, scattered specimens of the receptaculitid alga *Calathium* and the lithistid sponge *Archaeoscyphia* occur sporadically throughout this 500 ft. stratigraphic interval. In fact, Figure 31 shows the total ranges for these two organisms as seen in the Oklahoma localities.

It should be noted that, similar to the occurrence of the thin *Archaeoscyphia* horizon present in the middle of the Gorman Formation of central Texas, there is also a thin, rather persistent zone of scattered *Archaeoscyphia* fragments that occurs approximately 770 ft. below the top of the underlying Cool Creek Formation. However, this zone has only been found in the Arbuckle Mountains; persistent search of the Wichita Mountains localities has failed to delineate it.

## SUMMARY OF THE GEOLOGY OF THE WICHITA MOUNTAINS

The Wichita Mountains, outcropping as a series of relatively low hills and ridges in southwestern Oklahoma, emerge from a nearly flat plain whose relief is generally less than 500 ft.

Igneous rocks of Cambrian age (Ham et al., 1964) form the northwest-trending cores of the Wichita Mountains and are the dominant elements of the range.

Much sedimentary rock of Paleozoic age that was originally deposited on these igneous knobs have subsequently been removed by erosion from the central, and structurally highest, part of the mountain range. This occurred following intense orogeny and uplift during Pennsylvanian and Early Permian time (see Chase et al., 1956, p. 36; Ham & Wilson, 1967). As a result, older Paleozoic rocks are exposed in ridges and isolated hills on the eastern plunging end of the uplift. The exposed rocks are primarily carbonate units of Upper Cambrian and Lower and Middle Ordovician age, and these, in spots, are covered with clastics of Lower Permian age that form prominant plains around the Wichita Mountains.

Rocks of Lower Ordovician age are exposed in the eastern part of the Wichita Mountains, centering around the common corner of Comanche, Caddo, and Kiowa Counties, and in central Comanche County. All of the data available on the Lower Ordovician sequence in the Wichita Mountains has been painfully accumulated over a series of years beginning with the earlier reports of Taff (1928) and Decker (1939), and culminating with a series of guidebook reports by Ham. Foremost among these are: Ham & Frederickson (1947); Ham et al. (1949); and Ham et al. (1957). From these studies it has been determined that no complete sections of the Kindblade Formation are exposed in the Wichita Mountains. The most complete Kindblade sequence is located on the Kindblade Ranch, the type locality, where the lower 775 ft. is well exposed, but where the upper portion is covered by Permian sediments. For this project the Kindblade Ranch section was studied along with sections on Longhorn Mountain and Unap Mountain.

## SECTIONS IN THE WICHITA MOUNTAINS

**Unap Mountain Section.**—The stratigraphic relationships of the Kindblade organic buildups exposed at Unap Mountain are shown in Figure 32. Beds on the left side of the diagram are exposed in the quarry and can be traced eastward by relatively good outcrops to the scarp face beyond. The mounds occur within a 50 ft. interval characterized by the abundance of the receptaculitid alga *Calathium.* This mound interval, occurring approximately 500 ft. above the base of the Kindblade Formation, represents the highest stratigraphic occurrence of *Calathium, Archaeoscyphia,* and *Pulchrilamina.*

Mound to off-mound relationships are distinctive and clear-cut. The off-mound facies consists of thin-bedded limestones which terminate abruptly against the organic buildups. Off-mound lithologies are characterized by a lack of appreciable skeletal debris, except for the scattered occurrences of sponge fragments and scattered pods of digitate stromatolite colonies (fig. 33). The dominant rock is a slightly pelleted mudstone containing obvious organism burrow structures. By contrast, the moundrock is massive and contains relatively large, *in situ* biotic components, specifically stromatolitic structures, receptaculitid alga *Calathium,* the lithistid sponge *Archaeoscyphia annulata* Cullison, and, especially in the upper portion, coarsely silicified *Pulchrilamina spinosa* Toomey & Ham (fig. 34b). Petrologically, the moundrock can be classified as a skeletal wackestone-packstone containing variable amounts of intraclasts (fig. 35). Near the tops of the organic buildups, where *Pulchrilamina* is an obvious component, the rock is a boundstone. In many instances, large specimens of *Calathium* may be encrusted and joined to other skeletal fragments by the binding action of such problematical forms as *Renalcis* and *Epiphyton.* When this occurs, as shown in Figure 36, the rock may also be classified as a boundstone.

*Archaeoscyphia annulata* and *Calathium,* along with their spicular debris, are the most abundant biotic elements within the moundrock. Next in abundance is pelmatozoan debris, mostly scat-

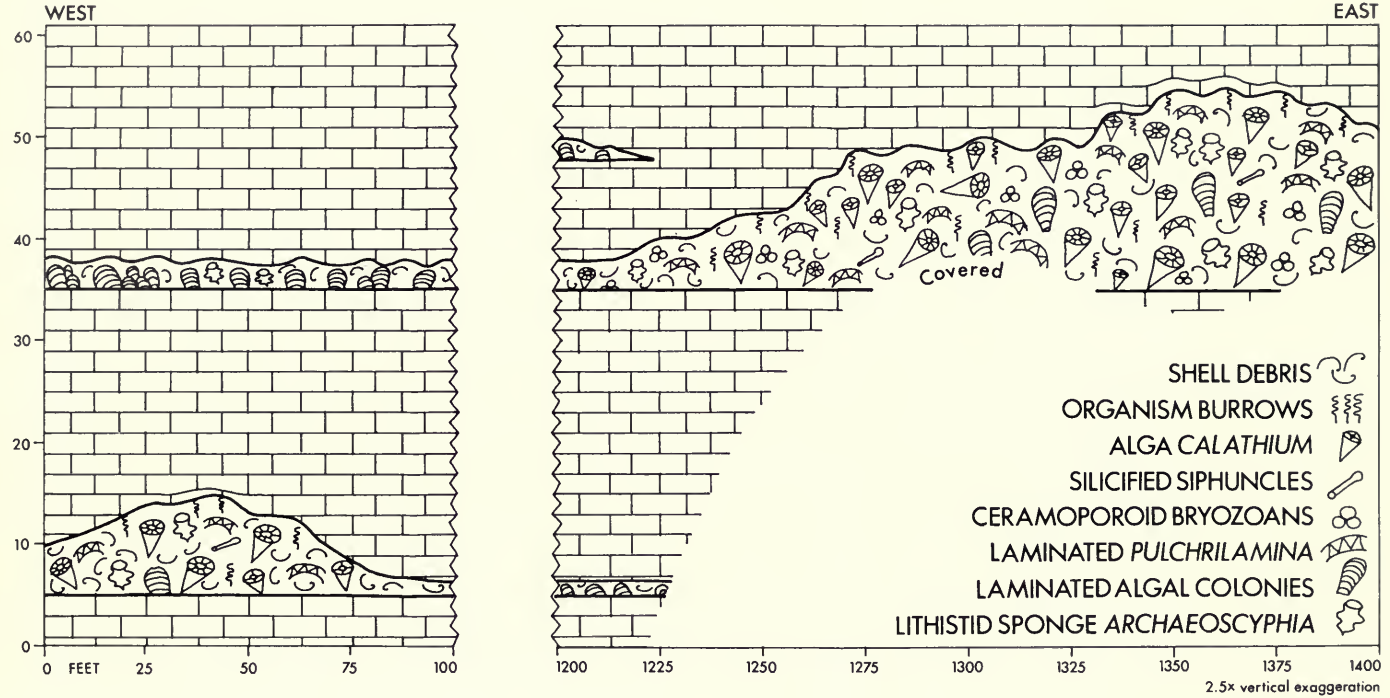
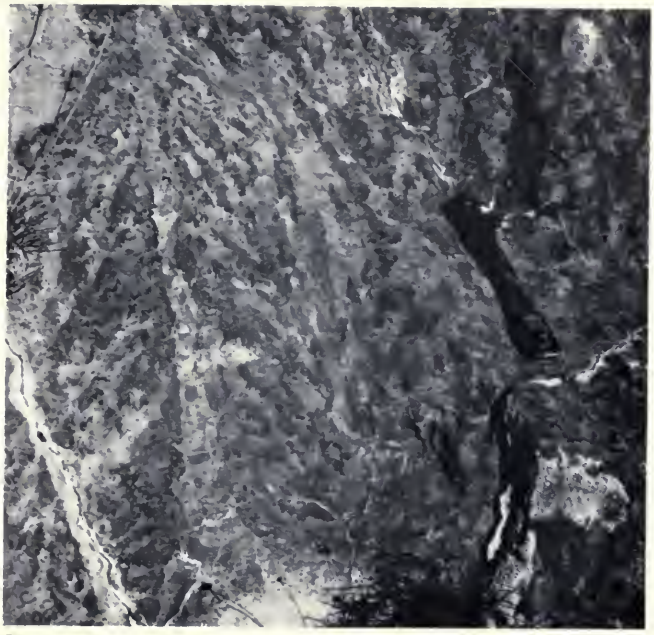



FIG. 32. Algal-sponge mounds in zone of abundant *Calathium* at the Unap Mountain section in the Wichita Mountains.



a

b

FIG. 33. Close-up photographs of various algal colonies present on Unap Mountain adjacent to the mound horizon 450 ft. above the base of the Kindblade Formation. (a) Pod comprised of digitate stromatolite colonies surrounded by intraclastic calcarenite, length of chisel is 7 in. (b) Individual stromatolite colonies surrounded by channels of lighter colored calcarenite; hammer, 15 in. long.

*a*

*b*

tered, and for the most part showing signs of algal(?) borings. *Epiphyton* and *Renalcis,* commonly in association with both *Archaeoscyphia* and *Calathium,* are locally abundant, as are silicified orthid brachiopods referable to the genus *Finkelnburgia.* Stromatolitic structures and tubules of *Girvanella* are present, though relatively uncommon. Other fossils found in the organic buildups occur in quantities that can be expressed only as rare to very rare. These include the bryozoan (ectoproct) *Ceramopora unapensis* Ross (Ross, 1966), high-spired gastropods *(Hormotoma* spp.) plus orospirid-type gastropods, trilobites, and coiled tarphycerid cephalopods. Formic acid etching of moundrock has also yielded distacodid conodonts (table 4), and a unique siliceous sponge spicule assemblage (Rigby & Toomey, 1978).

An overlay of a polished slab from this upper mound horizon is shown in Figure 37, and especially emphasizes the binding contribution by the encrusting forms *Renalcis* and *Pulchrilamina.*

At this location, the mound substrate shows a nice vertical sequence (fig. 38) of rapidly changing lithologies indicative of rapid subtidal sedimentation.

The lower mound horizon of an abundant zone of *Archaeoscyphia* is not very well exposed at the Unap Mountain section. However, scattered, rather small, algal-sponge organic buildups do occur. The dominant components appear to be stromatolitic algal material associated with clusters of the lithistid sponge *Archaeoscyphia annulata* Cullison. Acid etching of typical samples from this horizon yielded a few simple distacodid conodonts (table 3), and siliceous sponge spicules.

It is thought that abundant organic growth localized the organic buildups present at Unap Mountain and produced their unbedded appearance. The dominant organisms, particularly the clusters of lithistid sponges and receptaculitid algae, served as baffles, for the

---

*Opposite:*

FIG. 34. Outcrop photographs. **(a)** View of the lower Kindblade section at Unap Mountain section, Wichita Mountains, Kiowa County, southwestern Oklahoma. A few organic buildups (bed swellings) are seen in the upper one-third of the photograph. **(b)** Completely chertified colony of *Pulchrilamina spinosa* Toomey & Ham, a problematical laminated organism, present in the zone of abundant *Calathium* located approximately 450 ft. above the base of the Kindblade Formation at the Roosevelt Materials Company Quarry on Unap Mountain (in part from Toomey & Ham, 1967).

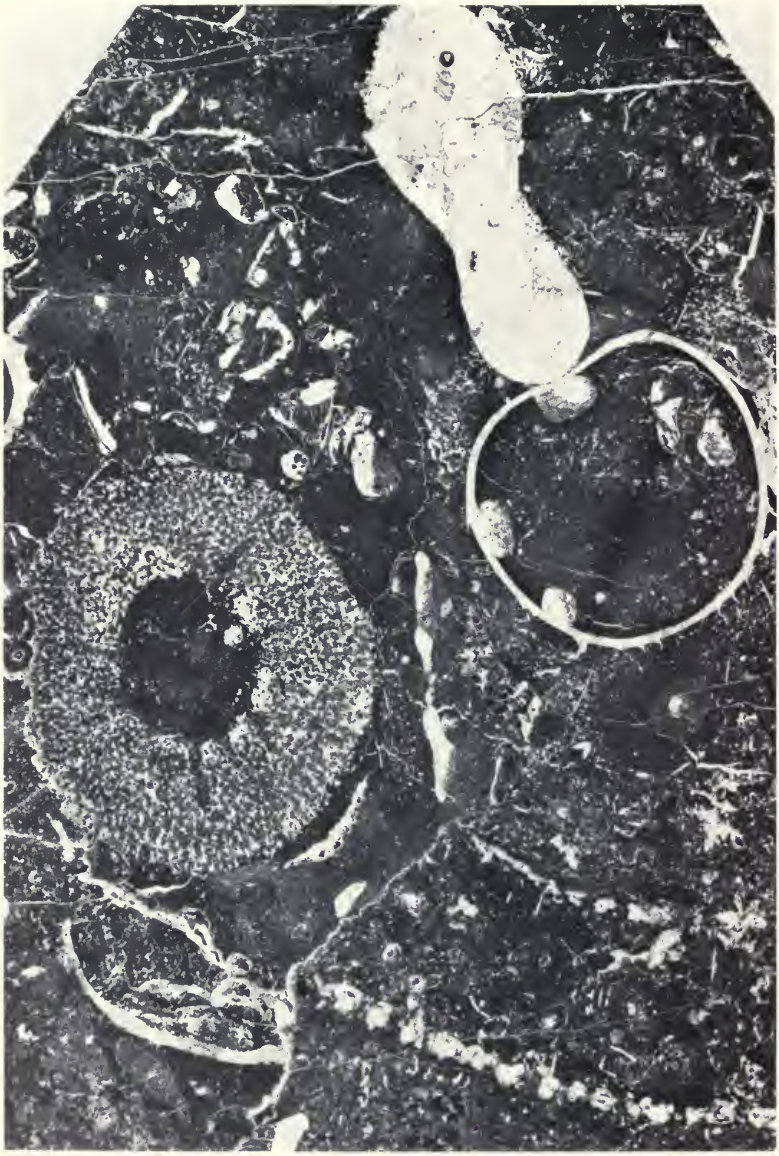


FIG. 35. Thin-section photomicrograph (×4) of typical moundrock (skeletal wackestone) from the zone of abundant *Calathium* located 450 ft. abaove the base of the Kindblade Formation on Unap Mountain. Photomicrograph shows a transverse cut through the lithistid sponge *Archaeoscyphia,* a large nautiloid cephalopod fragment (cf. *Tarphyceras*), a fragment of a rather large *Calathium*, organism burrows, and scattered shell debris.

FIG. 36. Thin-section photomicrograph (×3) of moundrock, in part boundstone, from the zone of abundant *Calathium* at the Unap Mountain section in the Wichita Mountains. Photomicrograph shows a large double-walled *Calathium* encrusted by colonies of the problematical organism *Renalcis*, which in turn has bound together two intraclasts composed entirely of lithistid sponge spicules (probably *Archaeoscyphia* fragments). Note organism burrows in the central cavity of the large *Calathium* specimen.

FIG. 37. Overlay of a polished slab from zone of abundant *Calathium,* Unap Mountain section, Wichita Mountains, southwestern Oklahoma.

calcium carbonate mud washed upon the buildups, but prevented currents from stratifying it as occurred in the off-mound facies. The lack of dipping flank beds strongly suggests that the organic buildups at no time attained any appreciable relief. Probably they rose no more than 3 to 5 ft. above the surrounding seafloor.

The abundance and diversity of the biota, and the lack of diagnostic features which might suggest subaerial exposure, such as mud cracks or erosion surfaces, or the development of a well-organized system of erosional channels, would indicate a shallow subtidal normal marine environment of deposition.

**Longhorn Mountain Section.**—This section is located a few miles southeast of the Unap Mountain section on a conspicuous ridge dominating the immediate area (fig. 39a). Both mound horizons are exposed at this location, although, as in the Unap Mountain section, the upper mound horizon is much better exposed (fig. 39b). In fact, at the Longhorn Mountain section the upper mound interval is better developed than at any other Oklahoma locality, and is the site of the largest Kindblade organic buildup found to date.

The lower mound horizon at this location is characterized by small mounds, less than 5 ft. in height, but containing an abundance of the lithistid sponge *Archaeoscyphia annulata* Cullison associated with a few *Calathium* and stromatolitic algae. Laterally adjacent to these rather small algal-*Archaeoscyphia* organic buildups are clusters of very small (maximum 15 in. in height with a diameter of 20 in.) algal mounds, sometimes referred to as miniherms (fig. 40a). These small mounds occur on the bedding plane surfaces of beds 50 to 60 ft. above the base of the Kindblade Formation at this location, and frequently on a surface that appears to be a lateral ripple-marked surface, with the mounds restricted to the tops of the ripples (fig. 40b). The mounds themselves are composed principally of laminated algal stromatolites whose surfaces are conspicuously marked by organism burrowing trails.

The upper mound interval is well developed at this location primarily through a stratigraphic interval approximately 400 to 450 ft. above the base of the Kindblade Formation. Organic buildups are interspersed throughout this interval, and here one can see well-developed lateral changes from massive, bedded organic buildups to thin-bedded off-mound-intermound rock. Most of these organic buildups average 15 ft. in length and range up to 10 ft. in height. The mound surfaces are strewn with the abundant silicified remains

(which closely resemble chert nodules) of the lithistid sponge *Archaeoscyphia annulata* Cullison, surficially silicified heads of the laminated organism *Pulchrilamina*, and the receptaculitid alga *Calathium* (fig. 41).

Petrologically, the moundrock can be classified as a silty, burrowed, intraclastic skeletal wackestone to boundstone. Many of the contained *Archaeoscyphia*, and some *Calathium* are completely circumscribed with colonial growths of the problematical algal? forms *Renalcis-Epiphyton;* see Figure 42 for a diagram of an overlay of a moundrock slab showing the abundance of encrusting growths.

It is worth noting that controversy surrounds the nature of *Renalcis;* Riding & Brasier (1975) regard *Renalcis* as one of the earliest calcareous foraminifers, whereas Hofmann (1975) believes that *Renalcis* represents remains of peripherally pigmented, gelatinous colonies of Chroococcalean algae which have undergone carbonate diagenesis involving obliteration of cell morphology.

Of especial note in the Longhorn Mountain section is the exposure of the largest Kindblade organic buildup found. This mound complex occurs approximately 408 ft. above the base of the formation and is 65 ft. in height and 175 ft. in length. The thick, massive moundrock contrasts sharply with the thin-bedded offmound strata. A schematic representation of this mound complex is shown in Figure 43. In this diagram, the relative abundances of the three dominant biotic components *Calathium*, *Archaeoscyphia*, and *Pulchrilamina* is indicated by symbols placed in various mound horizons. In the major organic development of the buildup, *Pulchrilamina* is dominant throughout, but the contribution of both *Calathium* and *Archaeoscyphia* varies, with *Calathium* abundant in

---

*Opposite:*

FIG. 38. Thin-section photomicrograph (×3) of the mound substrate (first few inches below the base of the mound) at the Unap Mountain section approximately 450 ft. above the base of the Kindblade Formation. Four distinct lithologies are apparent (from bottom to top): (1) dense mudstone with organism burrows; the burrows contain silt-size dolomite rhombs, and the upper portions of the burrows are infilled with intraclasts and skeletal debris from the overlying unit; (2) intraclastic wackestone made up of large irregular-shaped intraclasts with some skeletal debris, and grading upward into (3) well-sorted, laminated intraclastic unit with cyclic intervals of sparry and muddy matrices; skeletal debris, mostly gastropods, is common; contact with the overlying unit (4) is sharp and distinctive. This uppermost unit, on which the mound horizon rests, is an intraclastic packstone-wackestone with common echinoderm fragments.

a

b

FIG. 39. Outcrop photographs: **(a)** Longhorn Mountain looking southeast from Unap Mountain, Wichita Mountains, Kiowa County, southwestern Oklahoma. **(b)** Mound horizon in zone of abundant *Calathium* approximately 400 ft. above the base of the Kindblade Formation at the Longhorn Mountain section. Note the prominent mound in the center of the photograph.

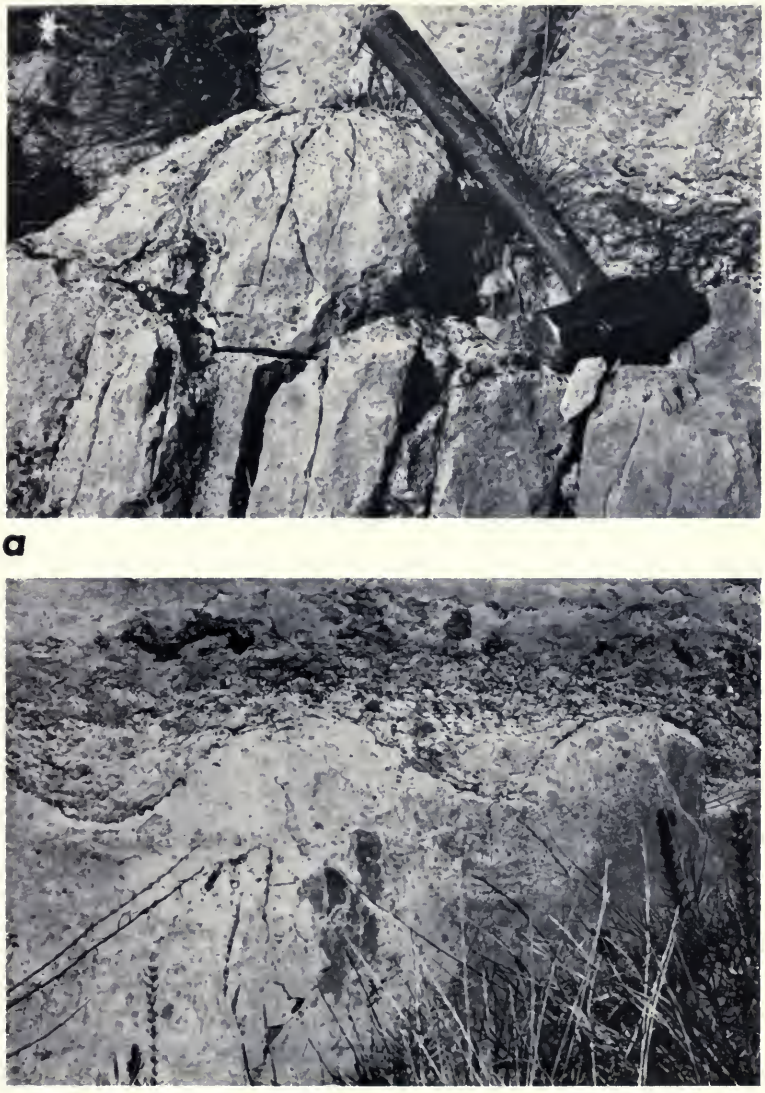


FIG. 40. Small algal mound structures (miniherms) that frequently occur on the bedding plane surfaces of lower Kindblade units 50 to 65 ft. above the base of the formation. These small mounds occur on beds lateral to the larger mound structures in the zone of abundant *Archaeoscyphia* at the Longhorn Mountain section, Wichita Mountains. **(a)** Mound structures are composed of laminated algal colonies and their surface is usually marked by numerous organism burrows. **(b)** Ripple-like sequence of algal mounds on the bedding plane surface; troughs between the "algal heads" contain thin-bedded dense mudstone.

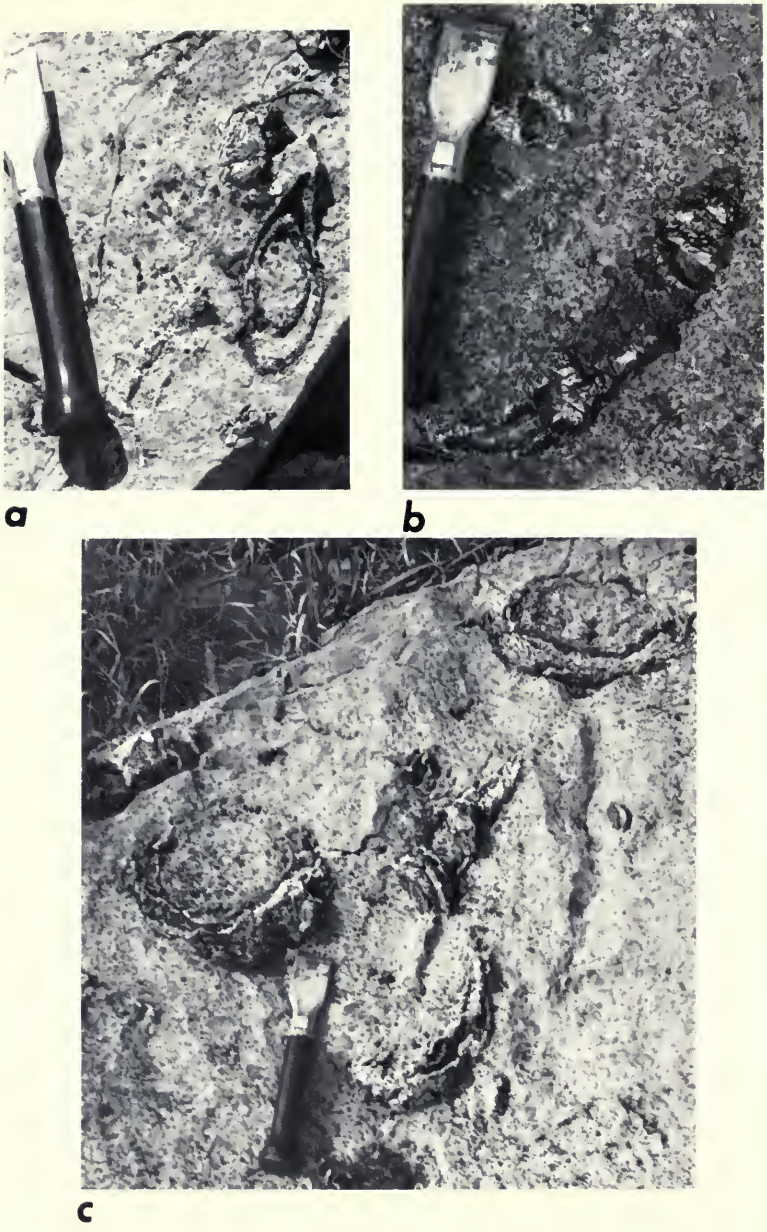



FIG. 41. Close-up photographs of silicified fossil remains occurring on the mound surfaces in the zone of abundant *Calathium* located approximately 400 ft. above the base of the Kindblade Formation at the Longhorn Mountain section. Length of chisel is 7 in. **(a)** Receptaculitid alga *Calathium* showing the characteristic double wall. **(b)** Lithistid sponge *Archaeoscyphia annulata* Cullison. **(c)** Surficially silicified heads of the laminated organism *Pulchrilamina*.

FIG. 42. Overlay of a polished slab of moundrock 408 ft. above the base of the Kindblade Formation at the Longhorn Mountain section, Wichita Mountains.

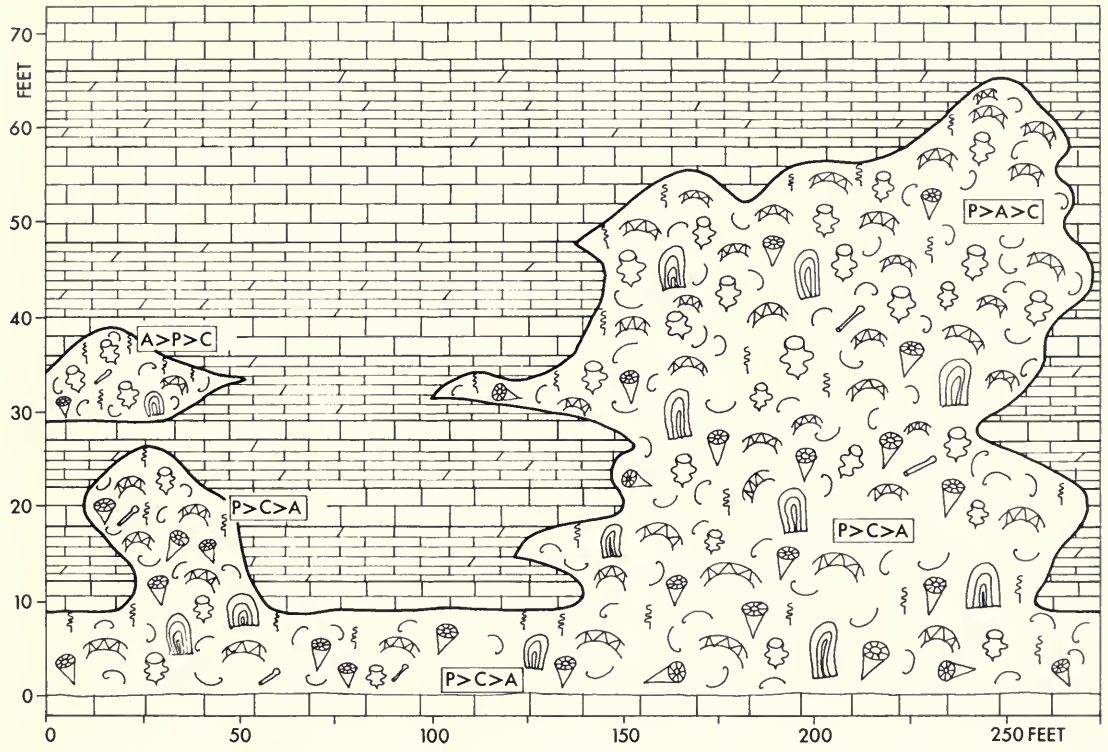



FIG. 43. Schematic diagram of mound complex 408 ft. above the base of the Kindblade Formation at Longhorn Mountain, Wichita Mountains.

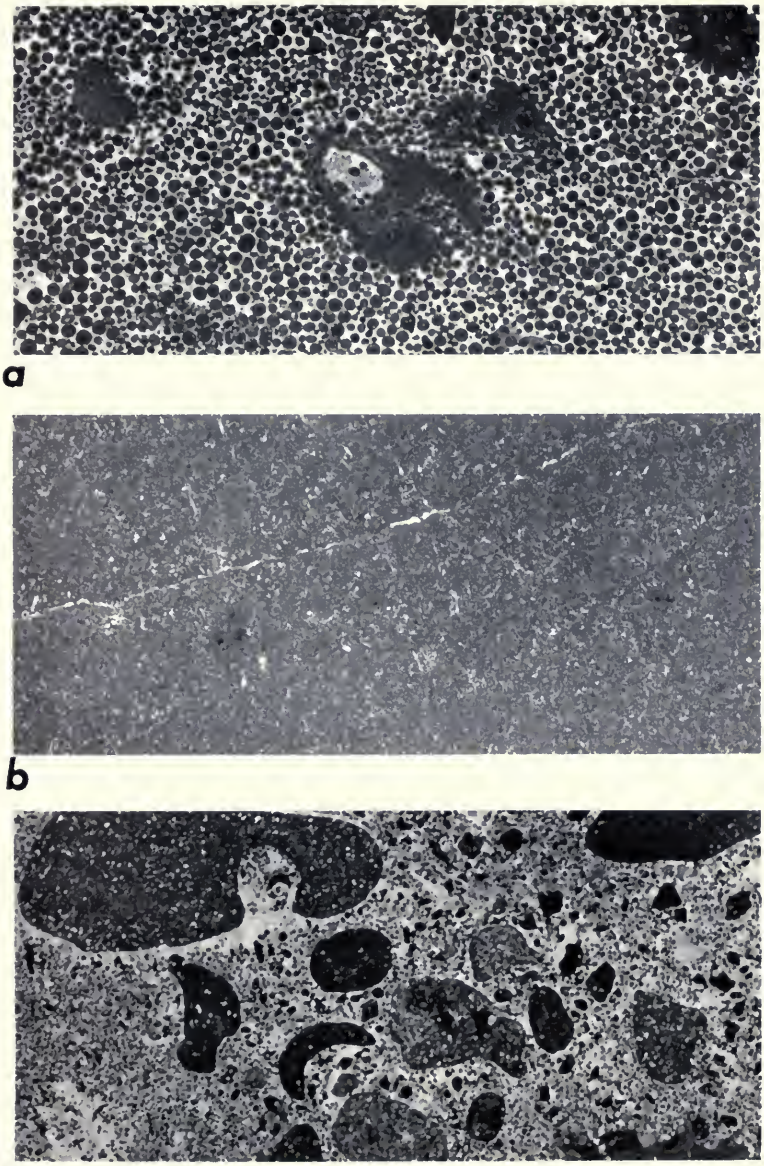



FIG. 44. Thin-section photomicrographs from off-mound rock units near the top of Longhorn Mountain, Wichita Mountains. (a) Oolitic-intraclastic grainstone, partly dolomitized ( × 4) from a rock unit 55 ft. above the base of the mound. (b) Slightly silty, pelletoidal-spicular mudstone with organism burrows ( × 7) from a rock unit 22 ft. above the base of the mound. (c) Silty, intraclastic-oolitic grainstone with fragments of echinoderms, gastropods, and trilobites ( × 4) from a rock unit 39 ft. above the base of the mound.

a

b

FIG. 45. Outcrop photographs taken at the Kindblade Ranch section, Kiowa County, Wichita Mountains of southwestern Oklahoma. (a) Lower portion of the Kindblade Formation as exposed from the contact of the Cool Creek-Kindblade Formations; note relatively thin units that grade laterally into massive mound buildups. (b) Close-up of a portion of the mound buildup shown in the above photograph. This buildup occurs within the zone of abundant *Archaeoscyphia* from 37 to 82 ft. above the base of the Kindblade Formation.

the middle portion of the buildup, but with *Archaeoscyphia* becoming dominant over *Calathium* near the top. The small satellite organic buildup shown on the left-hand side of the diagram is dominated by the lithistid sponge *Archaeoscyphia*, with *Pulchrilamina* and *Calathium* less abundant.

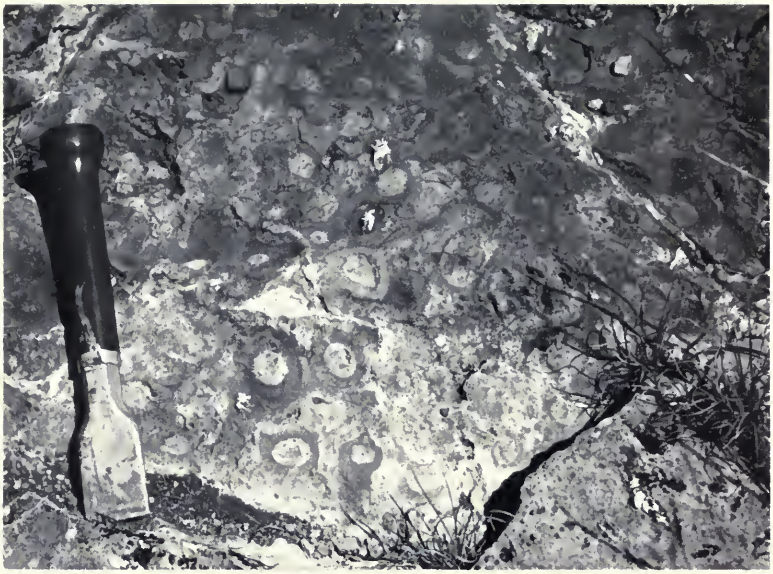
For the most part, off-mound strata consist of thin-bedded, dolomitic, burrowed, and pelletoidal mudstones (fig. 44b) intercalated with thicker-bedded skeletal calcarenites and intraclastic-oolitic grainstones (fig. 44a, c). Off-mound lithologies would tend to suggest deposition in shallow subtidal environments.

**Kindblade Ranch Section.**—This section is the type locality for the formation, and here the lower mound interval is better developed than anywhere else in the Wichita Mountains. Excellent exposures show thin-bedded carbonates laterally abutting into massive organic buildups (fig. 45). The organic buildup interval occurs within the zone of abundant *Archaeoscyphia* in a stratigraphic sequence 37 to 82 ft. above the base of the Kindblade Formation.

The organic buildups are numerous and consist of massive carbonate mounds up to 25 ft. in height and extend laterally for more than 100 ft. The surfaces of the organic buildups are strewn with scattered silicified specimens of the lithistid sponge *Archaeoscyphia annulata* Cullison, characteristically expressed as distinctive chert replacements (fig. 46b). Clusters of calcified *Archaeoscyphia* (fig. 46a) are also abundant and usually occur in pockets near the base of an individual organic buildup. The numerous organic buildups within this interval are massive, nonbedded, light-colored rocks that laterally change abruptly into thin-bedded, darker carbonates, usually mudstones (figs. 47, 48). It should be noted that within this mound interval there are no obvious flanking beds or even mound derived debris within the intermound beds. In fact, none of the abundant *Archaeoscyphia* of the mounds have been found in any of these beds at this location.

However, one thin intermound bed examined in this section could be classified as a burrowed skeletal wackestone. This unit contained no obvious megafossils, but a thin-section showed it to contain abundant sponge spicules, palmatozoan debris, gastropod shells, and trilobite debris. This bed is exceptional, as most intermound beds are mudstones devoid of much skeletal debris.

At an interval approximately 82 ft. above the base of the formation, and stratigraphically just above the lower zone of abundant



*a*

*b*

*Archaeoscyphia*, is a 4 ft. thick bed containing many small algal mounds "miniherms," as shown in the upper left-hand corner of Figure 48. These small organic growths are best seen on the bedding plane surfaces, and the largest are about 22 in. in diameter with a height of about 14 in. (fig. 49a). Characteristically, the surfaces of these mounds are covered with an anastomizing pattern of trails and burrows as shown on Figure 49b. Usually these trace fossils are infilled with dolomitized carbonate and/or chert and are white. These small organic structures are composed of laminated stromatolitic-like algal material.

Petrologically, the moundrock of the lower mound interval is a somewhat silty skeletal wackestone, which in some instances shows good evidence of algal binding (fig. 50). The lithistid sponge *Archaeoscyphia* is the dominant faunal component and *Calathium* can be rare-to-totally absent within some organic buildups. Some archaeoscyphid sponges have coatings of the encrusting problematical form *Renalcis*. *Pulchrilamina* is unrecognizable within this interval. Trilobite debris is fairly common, as are small gastropods, although pelmatozoan fragments are relatively rare. Significantly, a few chiton plates were seen in thin-section (fig. 50). Much of the moundrock is abundantly burrowed and usually contains some intraclasts.

The intermound beds shown on Figure 47 are dense mudstones containing only occasional, small, thin-shelled fragments. However, this rock does contain organism burrows, some of which still hold fecal pellets.

The upper mound interval is only poorly exposed at this section. At Kindblade Ranch the zone of abundant *Calathium* occurs at a stratigraphic interval 435-467 ft. above the base of the formation. Within this interval, organic buildups are small and not well developed. Partially silicified specimens of the receptaculitid alga *Calathium* are dominant, although some polished slabs prepared

---

*Opposite:*

FIG. 46. Outcrop photographs taken at the Kindblade Ranch section, Kiowa County, Wichita Mountains of southwestern Oklahoma. Both photographs taken on mound surfaces in the zone of abundant *Archaeoscyphia* located 40 ft. above the base of the Kindblade Formation. **(a)** Large cluster of calcified lithistid *Archaeoscyphia* at the base of an organic buildup; close count indicates at least 50 fairly large sponges closely packed together. **(b)** Chert replaced *Archaeoscyphia* usually found abundantly strewn over the surfaces of many organic buildups; chisel, 7 in. long.

FIG. 47. A typical mound buildup within the interval 65-82 ft. above the base of the Kindblade Formation in the zone of abundant *Archaeoscyphia* at the Kindblade Ranch section, Wichita Mountains, Kiowa County, southwestern Oklahoma. Note well-bedded rocks, in right side of photograph, abruptly going into massive, light-colored, non-bedded moundrock.

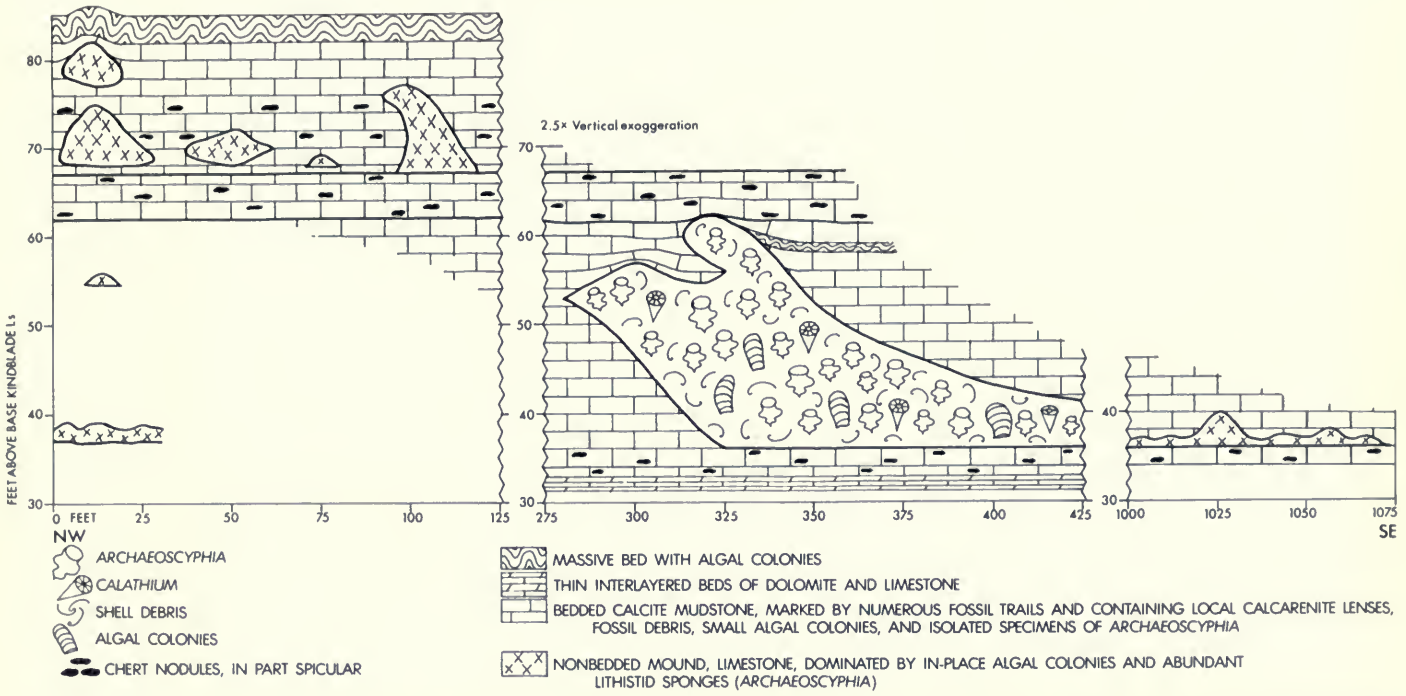



FIG. 48. Diagram of organic buildup complex in zone of abundant *Archaeoscyphia* at the Kindblade Ranch section in the Wichita Mountains.

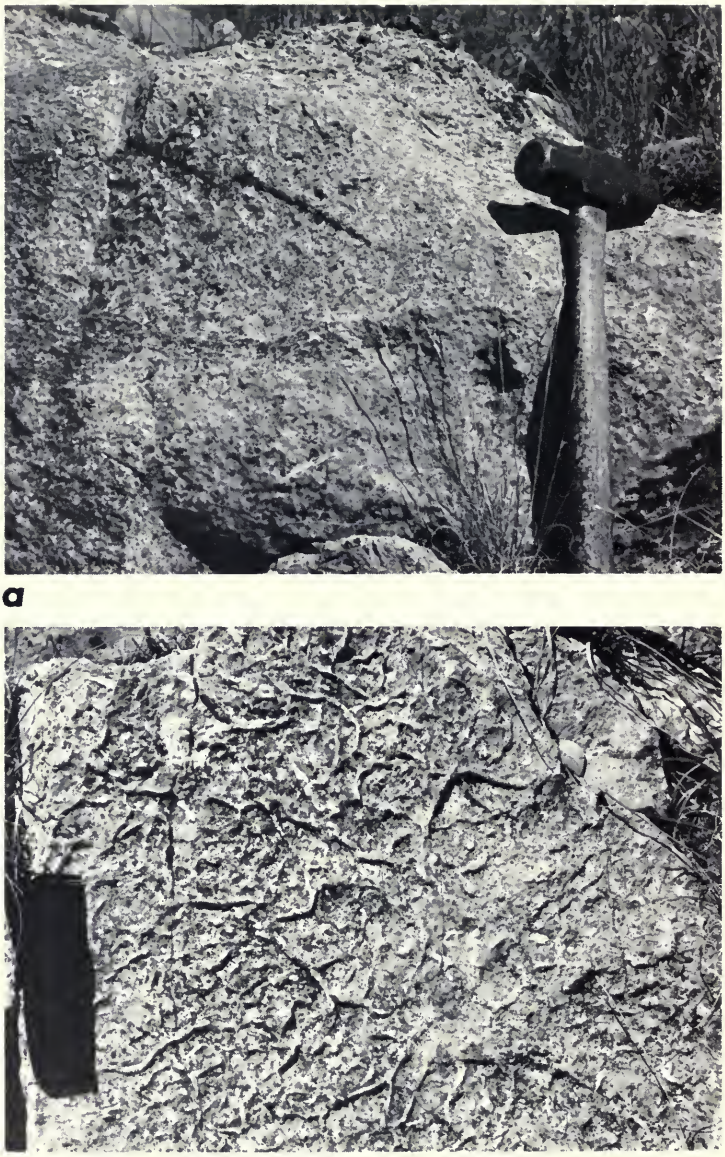



FIG. 49. Close-up outcrop photographs taken on the bedding plane surface 82 ft. above the base of the Kindblade Formation at the Kindblade Ranch section, Wichita Mountains. (a) Typical algal "miniherm" developed on the bedding surface. (b) Close-up of the mound surface showing the effect of extensive organism burrowing. Burrows are usually infilled with dolomitzed carbonate and/or chert.

FIG. 50. Thin-section photomicrograph ( × 3) of typical moundrock located 75 ft. above the base of the Kindblade Formation in the zone of abundant *Archaeoscyphia* at the Kindblade Ranch section in the Wichita Mountains. Rock may be classified as a skeletal wackestone to boundstone that is burrowed and contains a large fragment of the lithistid sponge *Archaeoscyphia*. Note the presence of algal laminae in lower portions of photomicrograph and skeletal debris, including trilobite material and a chiton plate, near the top of the photomicrograph.

TABLE 4. Conodont assemblages from the Lower Ordovician (Kindblade) horizons of abundant *Calathium* in southern Oklahoma.

| CONODONT IDENTIFICATIONS | ARBUCKLE GROUP KINDBLADE FORMATION | | | | | | |
|---|---|---|---|---|---|---|---|
| | ARBUCKLE MOUNTAINS | | | | WICHITA MOUNTAINS | | |
| | JOINS RANCH | HIGHWAY 77 | SOUTHERN TISHOMINGO ANTICLINE | MILL CREEK | UNAP MOUNTAIN | LONGHORN MOUNTAIN | Total number of specimens |
| 1. *Acodus* aff. *A. deltatus* Lindstrom | | | | | | | |
| drepanodiform-element | 1 | - | - | - | - | - | 1 |
| trichonodelliform-element | - | - | - | 1 | - | - | 1 |
| 2. *Drepanodus arcuatus* Pander | | | | | | | |
| arcuatiform-element | 3 | - | - | - | - | - | 3 |
| oistodiform-element | 1 | - | - | - | - | - | 1 |
| sculponeaform-element | 1 | - | - | - | - | - | 1 |
| 3. *D. homocurvatus* Lindstrom | 7 | - | - | - | - | - | 7 |
| 4. "*D.*" *subarcuatus* Furnish | 13 | 30 | 30 | 20 | 17 | 5 | 115 |
| 5. *D. suberectus* (Branson & & Mehl) | - | - | 1 | - | - | - | 1 |
| 6. drepanodiform-elements | 2 | 14 | 7 | 3 | 7 | - | 33 |
| 7. *Oneotodus simplex* (Furnish) | 1 | 8 | 15 | - | 4 | - | 28 |
| 8. *Paltodus distortus* Branson & Mehl) | - | - | 1 | - | - | - | 1 |
| 9. Aff. *P. inconstans* Lindstrom oistodiform-element | 5 | 5 | 3 | 5 | - | - | 18 |
| 10. "*Scandodus*" *americanus* Serpagli | - | - | 1 | - | - | - | 1 |
| 11. Aff. *S. furnishi* Lindstrom | 1 | - | - | - | - | - | 1 |
| 12. Aff. "*S.*" *robustus* Serpagli | 1 | 5 | 4 | - | - | 1 | 11 |

TABLE 4—*continued*

| Conodont Identifications | Arbuckle Group Kindblade Formation | | | | | | |
|---|---|---|---|---|---|---|---|
| | Arbuckle Mountains | | | | Wichita Mountains | | |
| | Joins Ranch | Highway 77 | Southern Tishomingo Anticline | Mill Creek | Unap Mountain | Longhorn Mountain | Total number of specimens |
| 13. *S. toomeyi* (Ethington & Clark) | - | - | - | 1 | 1 | - | 2 |
| 14. *Scolopodus gracilis* Ethington & Clark | - | 2 | - | - | - | 1 | 3 |
| 15. *S. iowensis* (Furnish) | - | - | - | - | 3 | - | 3 |
| 16. *S. quadriplicatus* Branson & Mehl | 10 | 4 | 33 | 3 | 12 | 7 | 69 |
| 17. Aff. *S. rex* Lindstrom | 7 | 2 | 5 | 5 | - | - | 19 |
| 18. *S. staufferi* (Furnish) | - | 5 | 5 | - | - | - | 10 |
| 19. *S. triplicatus* Ethington & Clark | 6 | 9 | 9 | - | 3 | 2 | 29 |
| 20. ?*S.* sp. | - | - | - | - | 3 | - | 3 |
| 21. *"Cordylodus" simplex* Branson & Mehl | - | 1 | - | - | - | - | 1 |
| 22. *Ulrichodina deflexa* Furnish | 2 | - | 4 | - | - | - | 6 |
| 23. *U. wisconsinensis* Furnish | - | 3 | - | - | - | - | 3 |
| 24. ?*U.* sp. | - | - | - | - | - | 1 | 1 |
| 25. *Walliserodus comptus* (Branson & Mehl) multicostate-element | - | 1 | - | - | - | - | 1 |
| quadricostate-element | - | 1 | - | - | - | - | 1 |
| 26. New genus and species eobelodiniform-element | - | - | 1 | - | - | - | 1 |
| TOTALS | 61 | 90 | 119 | 38 | 50 | 17 | 375 |

FIG. 51. Thin-section photomicrograph ( × 3) of moundrock located 467 ft. above the base of the Kindblade Formation in the zone of abundant *Calathium* at the Kindblade Ranch section, Wichita Mountains. Note the close association between *Calathium* remains and fragments of a lithistid sponge, probably *Archaeoscyphia*.

from this interval also show abundant calcified specimens. The lithistid sponge *Archaeoscyphia* is only poorly represented on mound surfaces; some calcified specimens are also seen on polished slabs. Certain *Pulchrilamina* is unrecognizable within this interval. Silicified orospirid-type gastropods and high-spired hormotomid-type gastropods are concentrated in pockets between the small *Calathium*-dominated mounds.

Petrologically, this moundrock can be considered as a silty, intraclastic, skeletal wackestone. Additional components include: *Renalcis,* some algal laminae with included *Girvanella* tubules, sponge spicules, brachiopod fragments, gastropods, and trilobite and pelmatozoan debris. Typical moundrock from this interval is shown in Figure 51, which shows a number of intraclasts that are composed solely of lithistid sponge fragments.

## BRIEF SUMMARY OF THE GEOLOGY OF THE ARBUCKLE MOUNTAINS

The early work on the geology of the Arbuckle Mountains of southcentral Oklahoma was done by Taff (1928) and Decker (1939). These two pioneer workers established the stratigraphic framework and initiated interest in the structural complexities of this thick rock sequence. Later, Ham, in a series of papers (notably 1951, 1955; Ham, Denison & Merritt, 1964; Ham et al., 1968), firmly established the stratigraphic and structural framework in which the regional geology could be described in detail.

In general, the Arbuckle Mountains consists of a huge inlier of folded and faulted Paleozoic and Precambrian rocks that are covered on the east, north, and west by gently dipping Late Paleozoic strata, and on the south by gently dipping Early Cretaceous sediments of the Gulf Coastal Plain. This inlier is roughly triangular, includes nearly 1,000 sq. miles, and is located almost in the center of the southern third of the state. The area is characterized mostly by excellent outcrops of carbonate rocks, principally Early Paleozoic carbonates and Late Paleozoic clastics. These carbonates and clastics were deposited partly upon a craton of Precambrian granites and partly in an adjoining geosynclinal basin. This entire rock complex was modified by Pennsylvanian orogeny into a single geographic unit.

The present Arbuckle Mountains consist of about 80 per cent gently rolling hills, with the greatest relief along U.S. Highway 77. There is a total relief of only 607 ft.

The Kindblade Formation is well exposed in the Arbuckle Mountains and consists primarily of thin to thick-bedded carbonates that characteristically crop out with dips as much as 60 deg., thus imparting to the sequence its unique "tombstone" appearance, as shown in Figure 56a. The most complete section of the Kindblade Formation occurs in the Arbuckle Anticline and is approximately

1,400 ft. thick (Ham, pers. comm., 1968). For this study, only the lowermost 500 ft. of the formation was considered (fig. 31). Accordingly, four sections were measured and collected, two of which are in the Arbuckle Anticline (Joins Ranch and Highway 77), and two are in the Tishimingo Anticline (South Part and Mill Creek). The pertinent details of these sections are given below.

## SECTIONS IN THE ARBUCKLE MOUNTAINS

**Joins Ranch Section.**—The Joins Ranch section is the westernmost sequence sampled in the Arbuckle Mountains. This section is located in Murray County and is shown in Figure 30 as section A.

Both the lower and upper mound intervals are exposed at the Joins Ranch, although outcrop relationships are much better developed in the thicker, lower mound horizon (zone of abundant *Archaeoscyphia*) (fig. 31).

The lower mound interval stratigraphically ranges from approximately 30 to 120 ft. above the base of the Kindblade Formation. This interval contains a number of mound horizons, usually averaging about 7 ft. in thickness and consisting of biostromal units that may characteristically mound-up laterally (see Figure 52 for a schematic representation of the field relations).

The mound horizons contain many small dome-shaped stromatolitic colonies (fig. 53a), which when cut open, show laminated stromatolitic algal growth. These algal heads are sporadically scattered within and throughout the mound horizons, but are usually fairly abundant, and may even be clustered near the tops of the rather small organic buildups. The algal heads are small, consistently averaging 14 in. in diameter, and are prominently exposed on the buildups. Specimens of *Archaeoscyphia annulata* Cullison are also abundantly scattered along the outcrop surfaces. For the most part, the archaeoscyphid specimens are chert replacements of the sponge internal cavity, the spongocoel (fig. 53b). These sponge remains average 3 to 5 in. in length. Rather poor, small specimens of *Calathium* are only rarely represented within this interval at this locality. Many rust-colored chert nodules are scattered throughout the mound horizons, and also in beds above and below. Thin-section examination of the chert nodules indicates that many are composed solely of sponge spicules, both monaxons and lithistids. Organism burrows are also conspicuous on outcrop

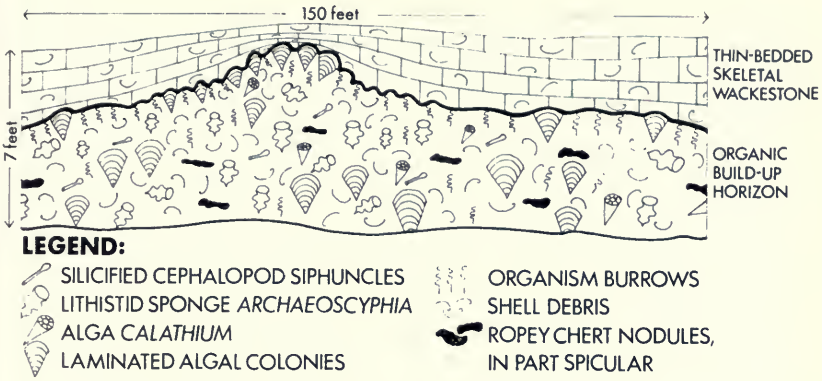



FIG. 52. Schematic diagram of a typical lower Kindblade *Archaeoscyphia*-bearing mound horizon at the Joins Ranch section in the Arbuckle Mountains, southern Oklahoma.

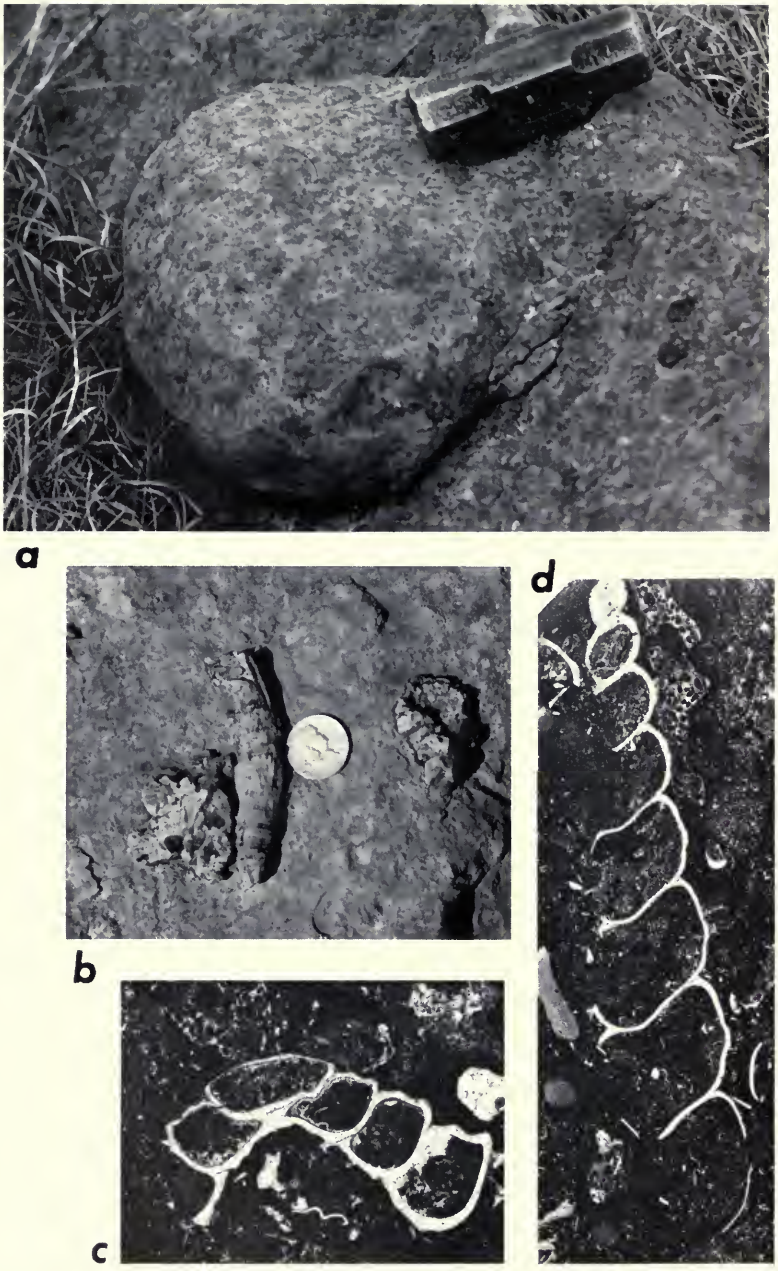
surfaces, although they are concentrated in and around the organic buildups. One other conspicuous faunal component noted within the mound horizons is the presence of silicified, slender endosiphuncular structures referred to *McQueenoceras* sp. Broken, unidentifiable shell debris, principally gastropods, brachiopods, and pelmatozoans, also occur. One large trilobite pygdium identified as *Goniotellina?* sp. was collected, and trilobite skeletal debris is commonly seen within the mound intervals.

Acid etching of moundrock has also yielded simple distocodid conodonts (table 3), and a unique siliceous sponge spicule assemblage (Rigby & Toomey, 1978).

Petrologically, the moundrock from the lower interval is slightly silty, intraclastic skeletal wackestone to boundstone, especially in those intervals where laminated stromatolitic material is well developed. Included allochems are tubules of the blue-green alga *Girvanella*, sponge spicules, pelmatozoan, brachiopod, gastropod, cephalopod, and trilobite debris. Organism burrows are also commonly seen in thin-section.

The upper mound interval at this locality is thinner and less well developed than the lower mound interval. It is stratigraphically 465 to 500 ft. above the base of the Kindblade Formation (fig. 31).

Sporadic, and rather poorly exposed outcrops mark this interval and prevent examination of the entire mound interval. However, one good exposure occurs at an interval 485 ft. above the base of the


a
b
c
d

formation and contains concentrations of organic structures in which clusters of the mostly silicified *Calathium* occur in abundance in mound-like concentrations. Polished slabs from moundrock of this horizon show that calcified *Archaeoscyphia* also occur commonly and are intimately associated with *Calathium* (fig. 54b), as are stromatolitic structures. Along with the sponges and algae are relatively common silicified specimens of an orospirid-type gastropod and silicified orthid brachiopods (*Finkelnburgia).* Rare occurrences of chiton plates, specifically *Ivoechiton calathicolus* (Smith & Toomey, 1964), and a few coiled cephalopods *(Tarphyceras chadwickense)* have also been found within these organic concentrations. Rare *Pulchrilamina* has also been identified (fig. 54a). Areas immediately surrounding the organic buildups contain concentrations of broken and abraded mound skeletal debris.

Petrologically, the moundrock from this interval can be described as slightly silty, intraclastic skeletal wackestone. When laminated algal stromatolitic material and concentrations of *Pulchrilamina* become abundant, the moundrock can be classified as a boundstone. The moundrock is conspicuously burrowed, and carries tubules of the blue-green alga *Girvanella* along with skeletal debris of the faunal components noted above. Examine Figure 53c,d for typical occurring gastropods and Figure 54 for thin-section photomicrographs from this horizon. Acid etching of moundrock from this interval has yielded simple distacodid conodonts. These are listed on Table 4.

As shown on Figure 31, a number of stratigraphic horizons, below and between the two major mound intervals, carry occasional *Calathium* and *Archaeoscyphia annulata.* For details of *Archaeoscyphia* see Figure 55.

Notably at the Joins Ranch locality, within a 1-ft. bed located approximately 770 ft. below the base of the Kindblade, in the middle of

---

*Opposite:*

FIG. 53. **(a)** Outcrop photograph of a domal stromatolite colony on the bedding plane surface marking the top of the Kindblade lower mound horizon 100 ft. above the base of the formation (width of hammer head is 6 in.). **(b)** Outcrop photograph of a chert replaced internal cavity (spongocoel) of the sponge *Archaeoscyphia* in the lower mound horizon 100 ft. above the base of the Kindblade at the Joins Ranch section. **(c)** Thin-section photomicrograph (×4) of a small turbinate orospirid-type gastropod, and **(d)** of a high-spired hormotomid-type gastropod (×2½), both from the zone of abundant *Calathium* located 485 ft. above the base of the Kindblade at the Joins Ranch section.

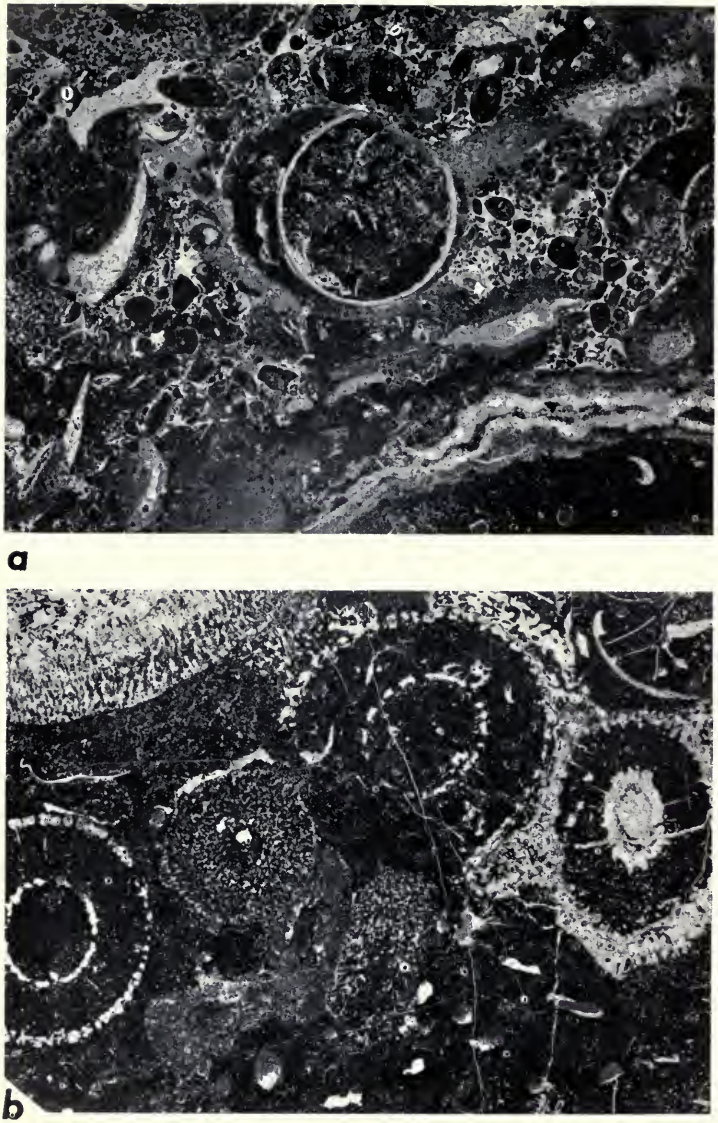



FIG. 54. Thin-section photomicrographs (× $2^{7}/_{10}$) of typical Kindblade upper moundrock from the zone of abundant *Calathium*, the upper mound horizon, 485 ft. above the base of the formation at the Joins Ranch section, Murray County, southern Oklahoma. **(a)** Intraclastic-skeletal rock with most of the skeletal material composed of gastropod fragments. Note sparry calcite laminations of *Pulchrilamina spinosa* Toomey & Ham in lower right-hand corner. **(b)** Sponge-algal wackestone showing a portion of an organic concentration. Transverse cut through the receptaculitid alga *Calathium* (larger, double-walled forms), and the smaller lithistid sponge *Archaeoscyphia*.

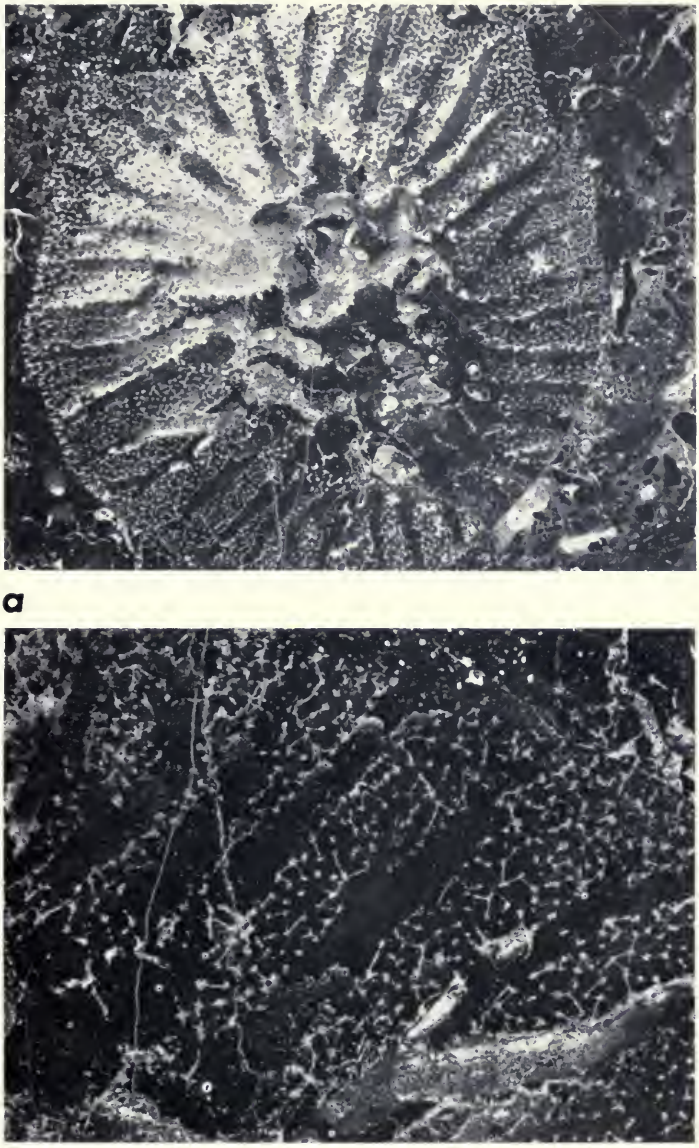
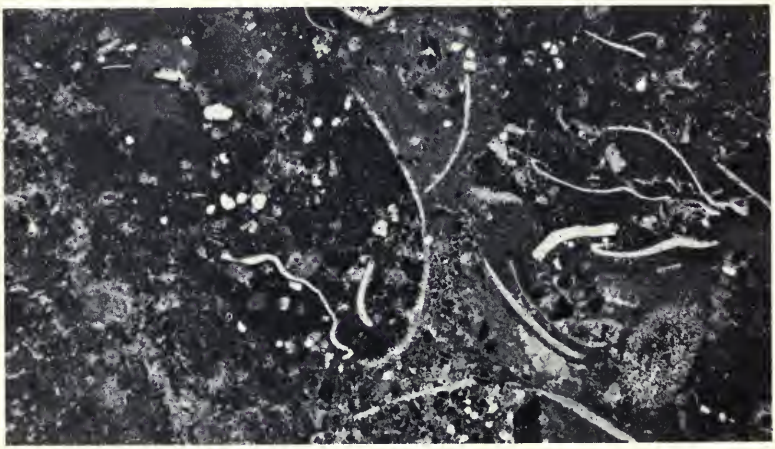


FIG. 55. Thin-section photomicrographs of transverse cuts through a calcified specimen of the lithistid sponge *Archaeoscyphia annulata* Cullison. (a) Whole specimen ($\times 2^{7}/_{10}$) from a sponge concentration at a stratigraphic interval 350 ft. above the base of the Kindblade Formation at the Joins Ranch section. (b) Closeup photomicrograph ($\times 8^{1}/_{2}$) of a portion of the wall of the above sponge showing the canals and the typical lithistid spicular network.

a



b

FIG. 56. (a) Outcrop photograph showing a portion of the Kindblade Formation exposed at the Highway 77 section, Carter County, Oklahoma. Beds of limestone dipping 55 to 60 deg. homoclinally southwestward on both sides of U.S. Highway 77 giving the section its characteristic "tombstone" appearence. (b) Thin-section photomicrograph (×5) of a skeletal wackestone in the zone of abundant *Archaeoscyphia* located 100 ft. above the base of the Kindblade Formation at the Highway 77 section. Note silt grains and intraclasts with trilobite shell debris; sample is also conspicuously burrowed.

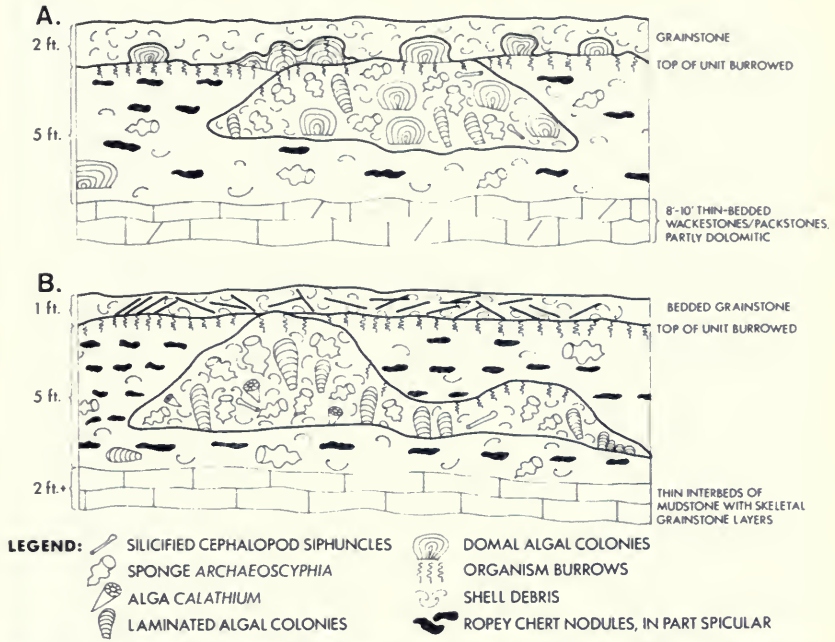



FIG. 57. Schematic diagrams of algal-sponge mounds in lower Kindblade Formation at Highway 77 section.

the underlying Cool Creek Formation, scattered chert replaced fragments of the lithistid sponge *Archaeoscyphia* occur. This horizon appears to be coeval with similar *Archaeoscyphia* occurrences from the Ellenburger middle Gorman interval in central Texas and from the lower El Paso Group of West Texas (fig. 1).

**Highway 77 Section.**—This section is located in the Arbuckle Anticline, Carter County, southern Oklahoma, and is plotted as section B on Figure 30.

At this section both the lower and upper mound intervals are exposed and their stratigraphic position is shown on Figure 31. As at Joins Ranch section, the best and most informative exposures in the Highway 77 section are of the lower mound interval (zone of abundant *Archaeoscyphia* in the Kindblade). Characteristically at this section, the carbonate beds dip homoclinally southwestward with dips of from 50 to 60 deg.

The lower mound interval is exposed as a series of biostromal units and organic buildups characterized by the abundance of the lithistid sponge *Archaeoscyphia annulata* Cullison. Stromatolitic

FIG. 58. Domal stromatolite colonies developed on the bedding plane surface of a mound horizon characterized by abundant *Archaeoscyphia* approximately 100 ft. above the base of the Kindblade Formation at the Highway 77 section. These small domal structures are composed of algally laminated stromatolites. The surface of the algal "miniherms" is usually conspicuously burrowed and may contain scattered chert replaced fragments of *Archaeoscyphia* and silicified cephalopod siphuncles; length of hammer is 15 in.

algae are also conspicuous organic components within these horizons and join with the sponges to create the organic mound structures. In the lower mound interval the receptaculitid alga *Calathium* occurs only rarely and is of secondary importance.

The principal beds containing zones of abundant *Archaeoscyphia* are stratigraphically located 80 to 175 ft. above the base of the Kindblade Formation. These organic-rich beds average approximately 5 ft. in thickness, and linear ropey chert nodules, in part spicular, occur throughout these units. Many chert replaced *Archaeoscyphia* and cephalopod siphuncles *(McQueenoceras)* are also associated with the chert layers.

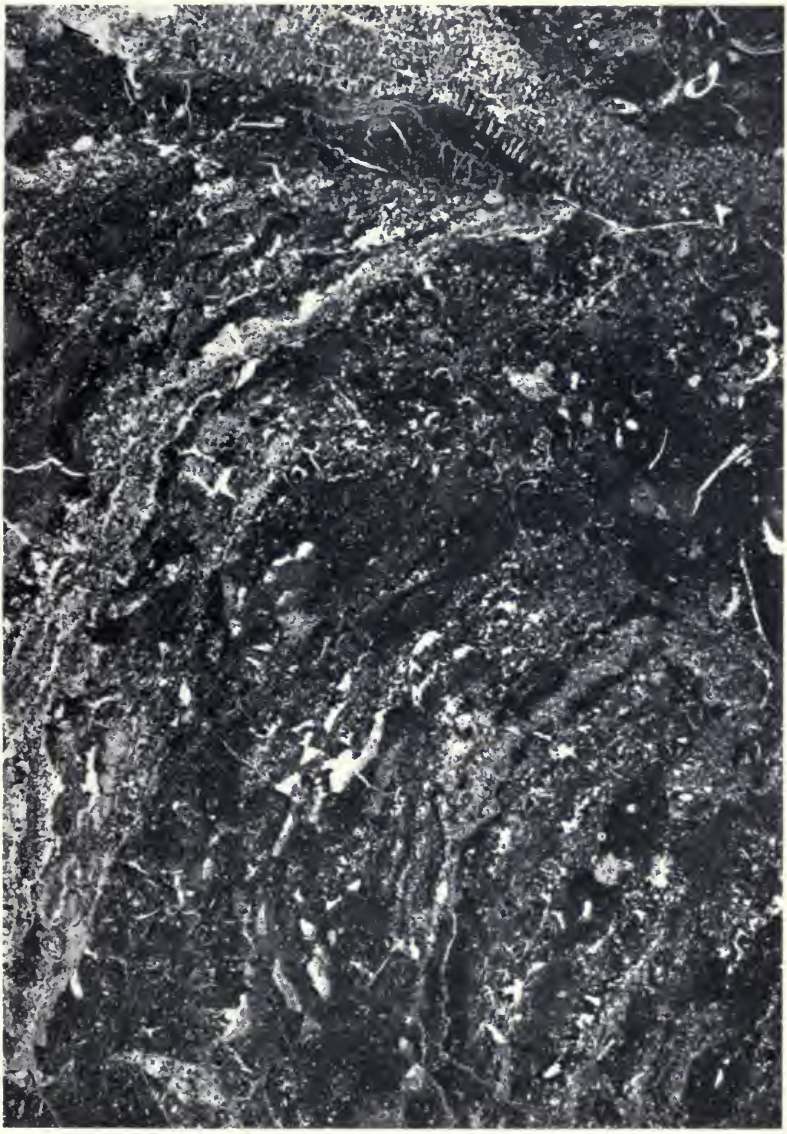


FIG. 59. Thin-section photomicrograph ( × 4) of stromatolitic boundstone from the main mound horizon 100 ft. above the base of the Kindblade Formation at the Highway 77 section. Note roughly parallel "algal" laminations delineated by the occurrence of fine quartz silt grains (small white flecks). Threads of the encrusting and perforating alga *Girvanella* are usually entwined along the laminae (not seen at this magnification). This boundstone also shows evidence of intensive organism burrowing.

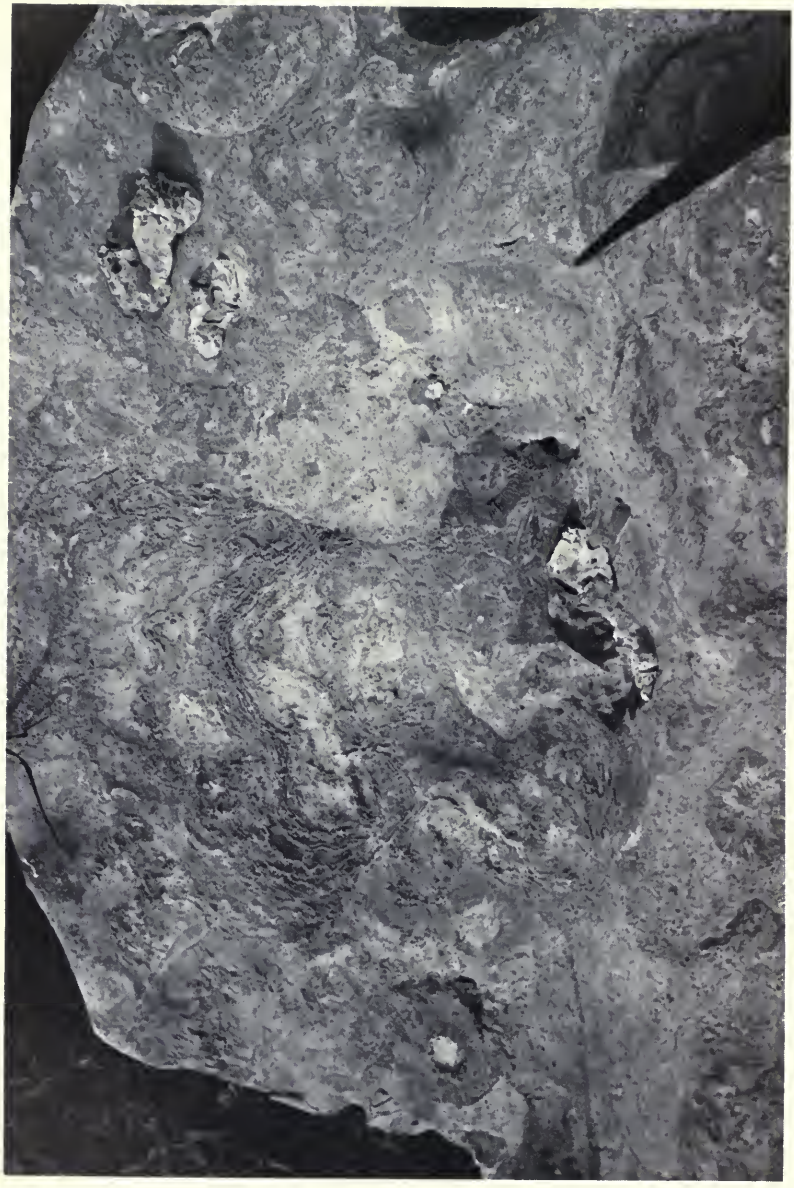


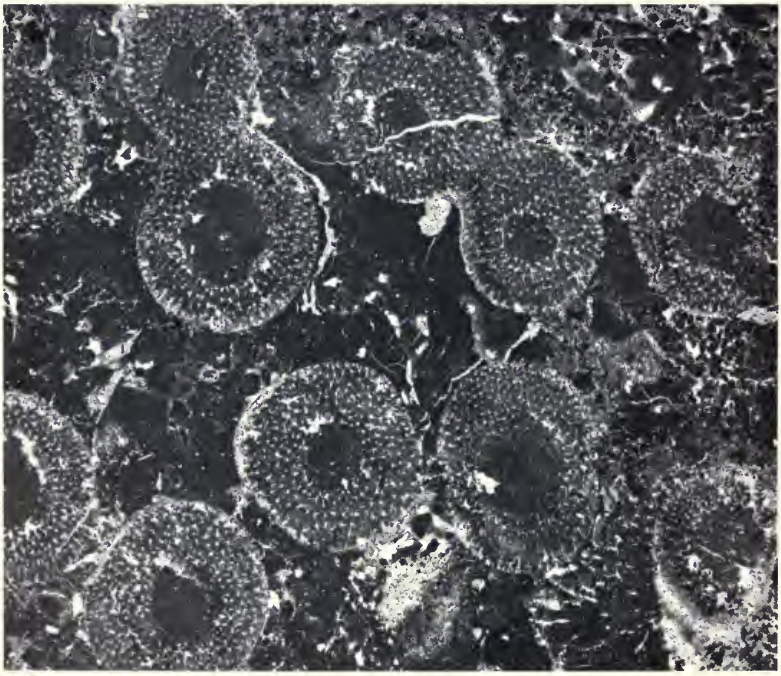
FIG. 60. Close-up photograph of the surface of a block of Kindblade limestone from the main mound horizon 100 ft. above the base of the formation at the Highway 77 section. Note the prominent stromatolitic algal colonies, and both calcified and silicified specimens of the lithistid sponge *Archaeoscyphia*. The areas between the algae and sponges contain fine shell debris, predominantly brachiopod, cephalopod, and trilobite fragments, along with abundant intraclasts.

Biostromal units rich in clusters of *Archaeoscyphia*, mainly as chert replacements, are locally common from the very base of the Kindblade Formation right up to the base of the lower mound interval.

Two types of organic buildups occur within the lower mound interval and these are schematically shown in Figure 57. The most commonly occurring organic buildups are shown in Figure 57a. The organic concentrations are podlike structures up to 2½ ft. high and 6 ft. long. They are emplaced within biostromal units and appear to represent localized areas of concentrated organic growth. Faunally, they are dominated by abundant *Archaeoscyphia* associated with abundant colonies composed of stromatolitic algae. The moundrock is of lighter color than the enclosing rock, and the contact with it is sharp. Scattered molluscan remains (gastropods and cephalopods) are common on the mound surfaces, along with light gray organism burrows that are partially silicified. The upper surface of many of the organic buildups appear to be truncated in part, and are overlain by conspicuous domal-shaped colonies of stromatolitic algae (fig. 58). In essence, these dome-shaped stromatolite colonies ("miniherms") developed on the eroded or truncated surfaces of the various mound horizons. The stromatolites are laminar boundstones (fig. 59) containing tubules of the blue-green alga *Girvanella*. Usually, the surfaces of these small (about 1 ft. high and 14 in. in diameter) organic buildups are covered with abundant organism burrows, and some even contain chert replaced fragments of *Archaeoscyphia*. Some of the algal colonies appear to be laterally-linked, although the majority are individual domes. These small organic buildups are overlain and surrounded by intraclastic skeletal grainstones.

Less common, are slightly larger organic buildups, averaging 3 ft. in height and up to 9 ft. in length (fig. 57b). These organic buildups are also emplaced within biostromal units with pronounced organism concentrations, and show sharp contact with the surrounding non-mound rock. Faunally, these organic buildups are dominated by clusters of *Archaeoscyphia annulata* Cullison, and vertical laminated stromatolitic algal colonies. Some shell debris, mainly molluscan and trilobite (fig. 56b), and a few specimens of *Calathium* occur within these buildups. The tops of the mound structures are conspicuously covered with organism burrows, as is the upper surface of the bed that grades off the mound horizon. Usually, the bed capping the mound horizon is a cross-bedded

*a*



*b*

grainstone whose allochems consist principally of mud intraclasts containing mixed skeletal debris. A typical exposure of a mound surface showing the principal organic components is shown in Figure 60.

Petrologically, the limestones from the lower mound horizons can be classified as silty, intraclastic skeletal wackestone to stromatolitic boundstone. Organic components consist of abundant *Archaeoscyphia*, stromatolitic colonies with tubules of *Girvanella*, and skeletal debris composed of sponge spicules, pelmatozoan debris, fragments of brachiopods, gastropods, cephalopods, trilobites, and ostracodes. Typical thin-section photomicrographs from the lower mound interval are given on Figure 61.

Many of the skeletal grains are circumscribed by thin micrite envelopes, and some of these grains show evidence of algal? borings. Well-rounded quartz silt grains are distributed throughout. The stromatolitic portions of the moundrock have a distinctive clotted or grumouse texture and much skeletal debris is entrapped within these organic swirls. Many of the stromatolitic colonies are channeled, and these are filled with packstones and grainstones composed of mud intraclasts with some contained skeletal debris. The intraclasts do show the effects of algal? borings, and the skeletal debris, predominantly pelmatozoan fragments, have pronounced calcite overgrowths.

As noted above, silicified *Archaeoscyphia* are abundant on the mounds; however, polished slabs show an abundant component of calcified *Archaeoscyphia* throughout the moundrock. The characteristic annulated wall structure is well shown on many specimens, some of which may reach a length of 8 in. Clusters of *Archaeoscyphia* (fig. 61b) occur rather commonly, and the outer surface of these clusters can be bound together by abundant colonies of the encrusting problematical form *Renalcis*. The receptaculitid alga *Calathium* is seen only rarely. Cephalopods are the only other large megafossils present in the lower mound horizons. The planispirally

*Opposite:*

FIG. 61. Thin-section photomicrographs of skeletal material from a mound horizon containing abundant *Archaeoscyphia* approximately 100 ft. above the base of the Kindblade Formation at the Highway 77 section. (a) Skeletal wackestone showing a cephalopod fragment whose chambers are infilled with mud, intraclasts, and quartz silt grains ( × 4). (b) Skeletal wackestone with whole specimens of the lithistid sponge *Archaeoscyphia*. Note the pronounced sponge spicular network, and the presence of intraclasts in upper right-hand corner of photomicrograph ( × 3).

FIG. 62. Thin-section photomicrograph ( × 3) of a boundstone stromatolite colony 462 ft. above the base of the Kindblade Formation at the Highway 77 section. The stromatolite laminae are delineated by quartz silt grains (tiny white flecks). The dense dark border around the stromatolite consists mainly of masses of *Girvanella* tubes. Note packstone channels, containing much shell debris, on either side of the stromatolite.

FIG. 63. Thin-section photomicrograph of a silty algal boundstone ( × 4) from the main mound horizon containing abundant *Calathium* at the Highway 77 section. This Kindblade interval is approximately 500 ft. above the base and contains much shell debris caught up in swirls of stromatolitic material. Note the entrapped chiton plates (inverted V's) in cross-section. The sharp contact at the upper right corner of the photomicrograph marks the intermound channel area containing abundant intraclasts set in a sparry calcite matrix.

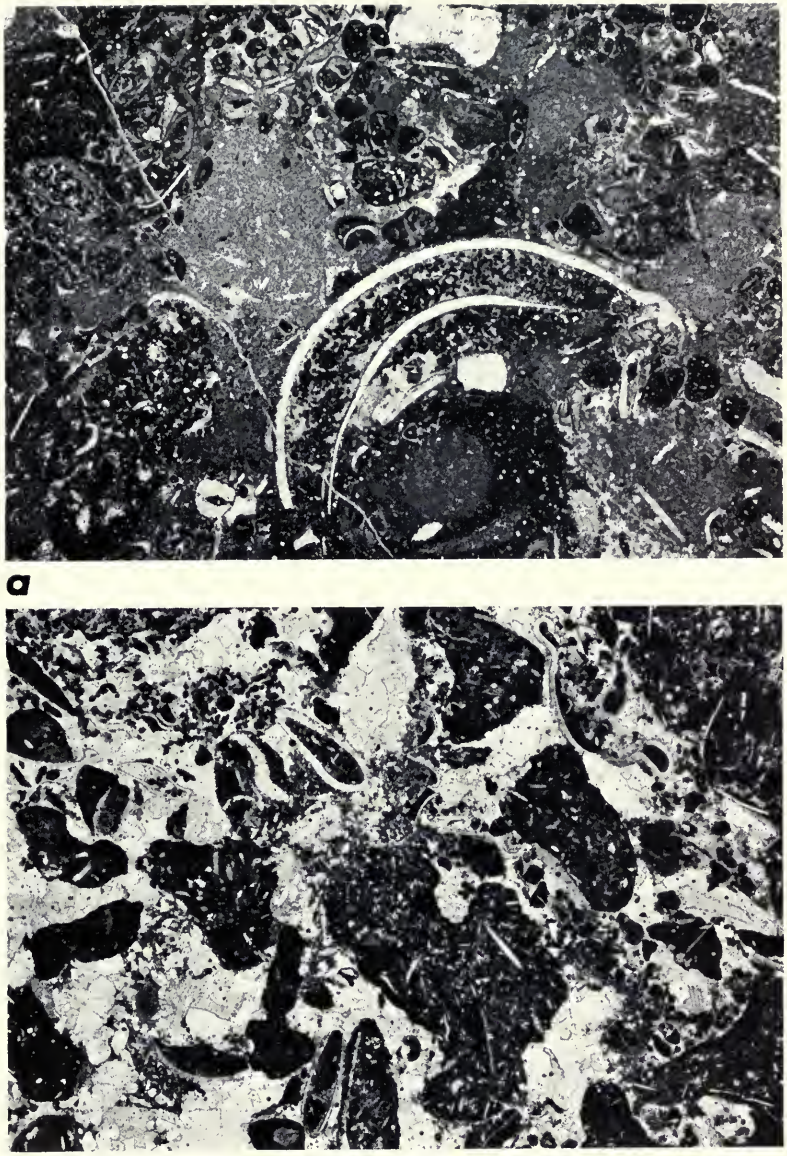


FIG. 64. Thin-section photomicrographs ( × 8) of mound horizon units in the zone of abundant *Calathium* at the Highway 77 section: **(a)** From 462 ft. above the base of the Kindblade; rock is an intraclastic skeletal wackestone that shows evidence of intensive organism burrowing. **(b)** From 500 ft. above the base of the Kindblade Formation, a typical intermound channel grainstone-packstone composed principally of mud intraclasts (note sponge spicules in largest intraclast).

coiled form *Tarphyceras* is present in units close to the very base of the Kindblade Formation, and is sporadically distributed throughout all of the units containing abundant *Archaeoscyphia* concentrations. Some tarphycerids attain a diameter of 3 in. Silicified cephalopod siphuncular structures are also rather common and many occur throughout the lower 100 ft. of the Kindblade Formation. Silicified siphuncles referred to *McQueenoceras* occur within the organic buildups.

Small turbinate gastropods occur ubiquitously and are especially conspicuous in rock units with much stromataolitic material. Orospirid-type gastropods, up to 1 in. in diamater, occur in many beds, especially in those containing organic buildups. Shell debris on the mounds is dominantly molluscan and trilobite, with only rare instances of orthid brachiopod occurrences. Acid etching of mound-rock yielded monaxon, lithistid, and octactine sponge spicules, along with common distacodid conodonts (simple cones) (table 3).

A very poorly exposed interval containing only small silicified fragments of the lithistid sponge *Archaeoscyphia* is located in the Cool Creek Formation, approximately 770 ft. below the contact with the overlying Kindblade Formation. This horizon is similar to that noted above in the description of the Joins Ranch section.

Organic buildups containing abundant receptaculitid alga *(Calathium)* are poorly exposed at this section in a stratigraphic interval, approximately 460 to 500 ft. above the base of the Kindblade Formation, and may be up to 5 ft. in height and from 8 to 10 ft. in length. Characteristically, they are separated from each other by intermound areas or channels that are filled with coarse clastic skeletal debris.

In the upper mound horizons, specimens of the receptaculitid alga *Calathium* are generally silicified and are much more abundant than specimens of *Archaeoscyphia.* The archaeoscyphids are usually found as chert replacements, but well-preserved calcified forms are also common. A number of the calcified archaeoscyphids show the distinctive wall annulations characteristic of this species. The largest collected archaeoscyphid specimen has a length of 10 in. with a spongocoel diameter of 1½ in.

Individual vertical stromatolite colonies, in part laterally-linked, are common within the mound horizons (fig. 62). These stromatolites are conspicuously laminated, with the laminae delineated by quartz silt grains entwined with *Girvanella* tubules.

The individual stromatolites are up to 3 in. in height and are separated from one another by grainstone-packstone channels filled with mud intraclasts and varied skeletal debris.

Molluscan remains are the only other conspicuous megafossils found within this interval. Especially noteworthy is the presence of chiton plates represented by *Gotlandochiton hami* (Smith & Toomey, 1964). Chiton plates are easily identified in thin-section by their characteristic V-shape (fig. 63), and some are even entrapped within stromatolitic algal swirls. Silicified cephalopod siphuncles referred to *McQueenoceras* (the dominant form), *Campbelloceras,* and *Shumardoceras* occur sporadically. A few silicified internal molds of a high-spired gastropod (cf. *Hormotoma*) occur only rarely. Brachiopod remains are very rare and consist of a few poorly preserved silicified orthid types.

Some of the skeletal grains from the mound intervals are circumscribed by thin micrite envelopes, and the grains show only the very beginnings of algal? borings. A few dasycladacean algal fragments were seen in one thin-section, and these appear to be *Vermiporella?* Some concentrations of *Calathium* have well-developed colonies of *Renalcis* encrusting their outer surfaces. *Pulchrilamina* has not been seen at this location.

Typical thin-section photomicrographs of intraclastic skeletal wackestone and an intermound channel grainstone-packstone are shown in Figure 64. The channels, when well exposed, may be up to 1 ft. in diameter. The dominant grains are rather large mud intraclasts that contain abundant sponge spicules.

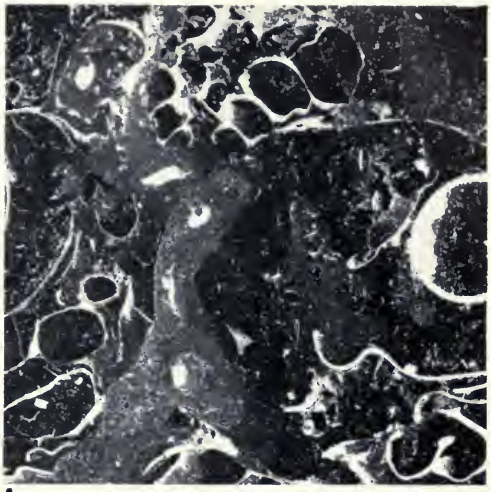
Simple, distacodid conodonts have been retrieved from both the moundrock and channel rock of the upper mound interval and are listed in Table 4.

**Southern Tishomingo Anticline Section.**—This section is located in Johnson County in the southern part of the Tishomingo An-

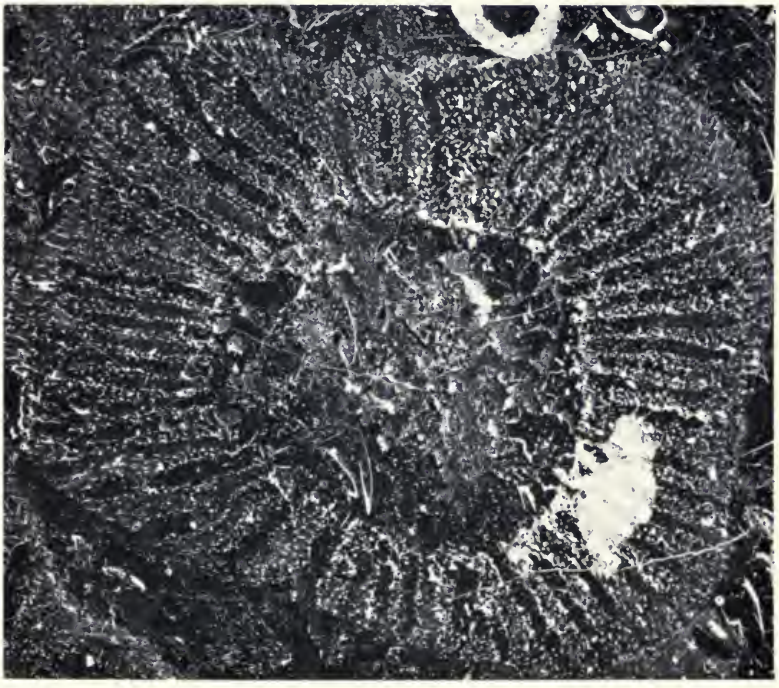
*Opposite:*

FIG. 65. Thin-section photomicrographs (all ×2½) from the zone of abundant *Archaeoscyphia* located stratigraphically 100 ft. above the base of the Kindblade Formation at the Southern Tishomingo Anticline section, Arbuckle Mountains, Johnston County, southern Oklahoma. (a) Coiled cephalopod cf. *Tarphyceras* sp. (b) Typical moundrock showing much skeletal debris, mainly gastropods; lighter areas reflect intense organism burrowing usually present in this horizon. (c) Transverse cut through the lithistid sponge *Archaeoscyphia* showing the pattern of canals leading into the large central cavity (spongocoel); white area on photomicrograph is region of incipient silicification.

a



b



c

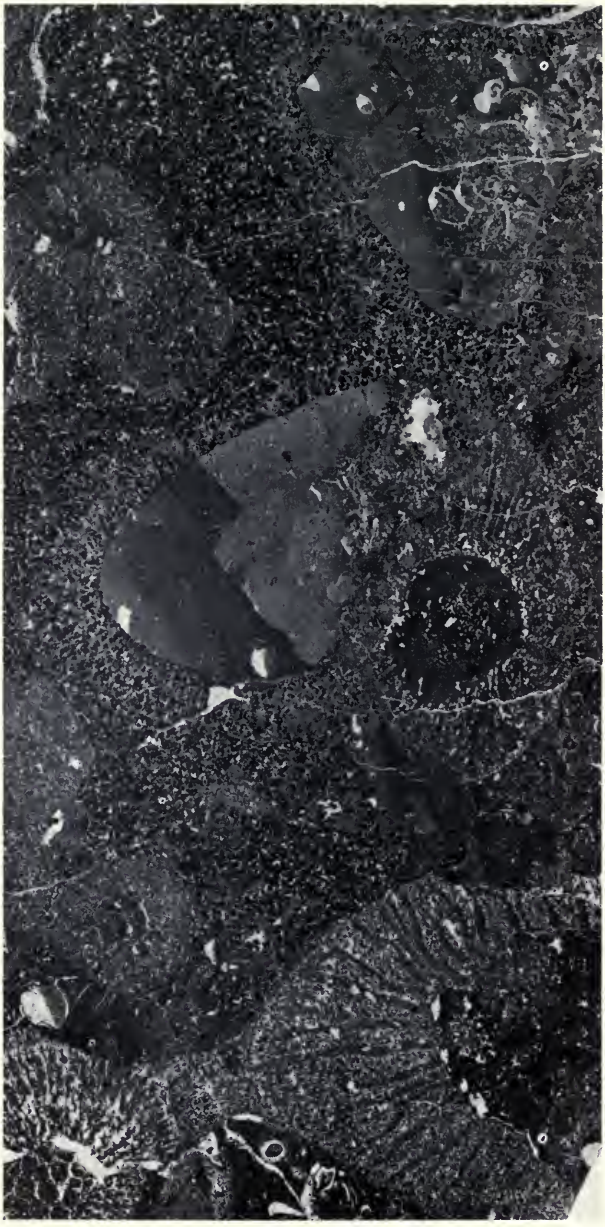
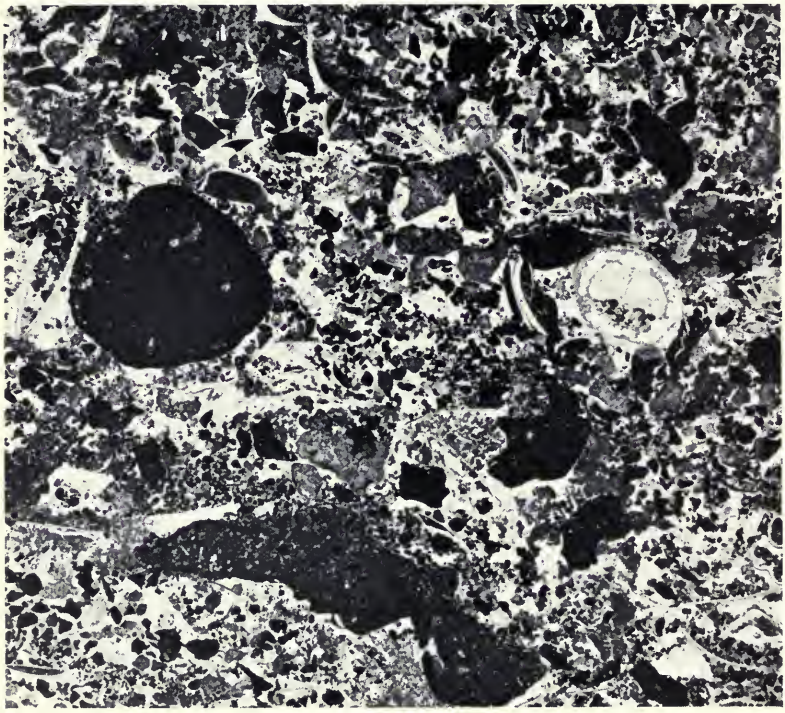


FIG. 66. Thin-section photomicrograph (×3) from the zone of abundant *Archaeoscyphia* at the Southern Tishomingo Anticline section. The outer edges of the sponges, and a few intraclasts, are encrusted by *Renalcis* (black dots), an organism of questionable biological affinity.

FIG. 67. Thin-section photomicrograph ( × 4) of typical moundrock from the zone of abundant *Calathium* at the Southern Tishomingo Anticline section, 450 ft. above the base of the Kindblade Formation. This rock type is classified as a skeletal wackestone containing abundant remains of the receptaculitid alga *Calathium* (top of figure) with common occurrences of the lithistid sponge *Archaeoscyphia* (bottom of figure). Note the close relationship between these two organisms that compose the dominant biotic components of the organic buildups within this stratigraphic interval.

a



b

FIG. 68. (a) Outcrop photograph showing small, mound-like structures on the bedding plane at a stratigraphic interval 25 ft. above the base of the Kindblade Formation at the Mill Creek section, Murray County, Arbuckle Mountains, southern Oklahoma; hammer is 15 in. long. (b) Thin-section photomicrograph (×4) of the above; rock can be classified as an intraclastic grainstone-packstone containing fragments of algae?, echinoderms, gastropods, and trilobites.

ticline. The locality is plotted as section D on Figure 30, and the stratigraphic sequence for this section is given on Figure 31. Both the lower and upper mound intervals are fairly well exposed at this location.

The lower mound interval is stratigraphically located approximately 95 to 170 ft. above the base of the Kindblade Formation. Below the lower mound interval, clusters of *Archaeoscyphia* are associated with small stromatolitic algal heads in a number of horizons. At an interval 95 ft. above the base of the formation, small organic buildups, up to 5 ft. in height and with variable width, are apparent in a number of horizons. The organic buildups are morphologically similar to those described from the Joins Ranch section as shown on Figure 52.

On outcrop, the dominant faunal element is massive clusters of the lithistid sponge *Archaeoscyphia annulata* Cullison, the majority of which are calcified (fig. 65c). The sponges are rather large (up to 12 in. in length) and well preserved. Sponge wall annulations, a characteristic of the species, are commonly seen on outcrop surfaces. Much stromatolitic material, specifically small (usually less than 12 in. in height) laminated algal colonies are intimately associated with the sponge clusters. Only a very few calcified specimens of the receptaculitid alga *Calathium* were identified from this interval. Slender, silicified endosiphuncular structures (cf. *McQueenoceras)* and coiled nautiloids referred to *Tarphyceras* (up to 3 in. in diameter) are also common on the organic buildups (fig. 65a), as are various small gastropods (fig. 65b).

Petrologically, moundrock from the lower mound interval can be classified as intraclastic sponge wackestone to boundstone. The rock is dominantly composed of calcified specimens of *Archaeoscyphia*, many of which appear to be bound together by encrusting growths of the problematical organism *Renalcis* (fig. 66). The rock is burrowed, and some skeletal grains show algal? borings along their peripheries. Skeletal debris is scattered and consists of sponge spicules, possible dasyclad algal fragments, and debris of pelmatozoans, brachiopods, gastropods, cephalopods, and trilobites.

Acid residues from the lower interval moundrock have yielded abundant monaxon and lithistid sponge spicules along with simple distacodid conodonts. The conodonts are listed on Table 3.

The upper mound interval is located stratigraphically approx-

a

b

FIG. 69. Close-up outcrop photographs taken of the surface of the zone of abundant *Archaeoscyphia* located 100 ft. above the base of the Kindblade Formation at the Mill Creek section. **(a)** Chert replaced specimen of the lithistid sponge *Archaeoscyphia*. **(b)** Silicified specimen of the receptaculitid alga *Calathium* showing the characteristic double-walled structure.

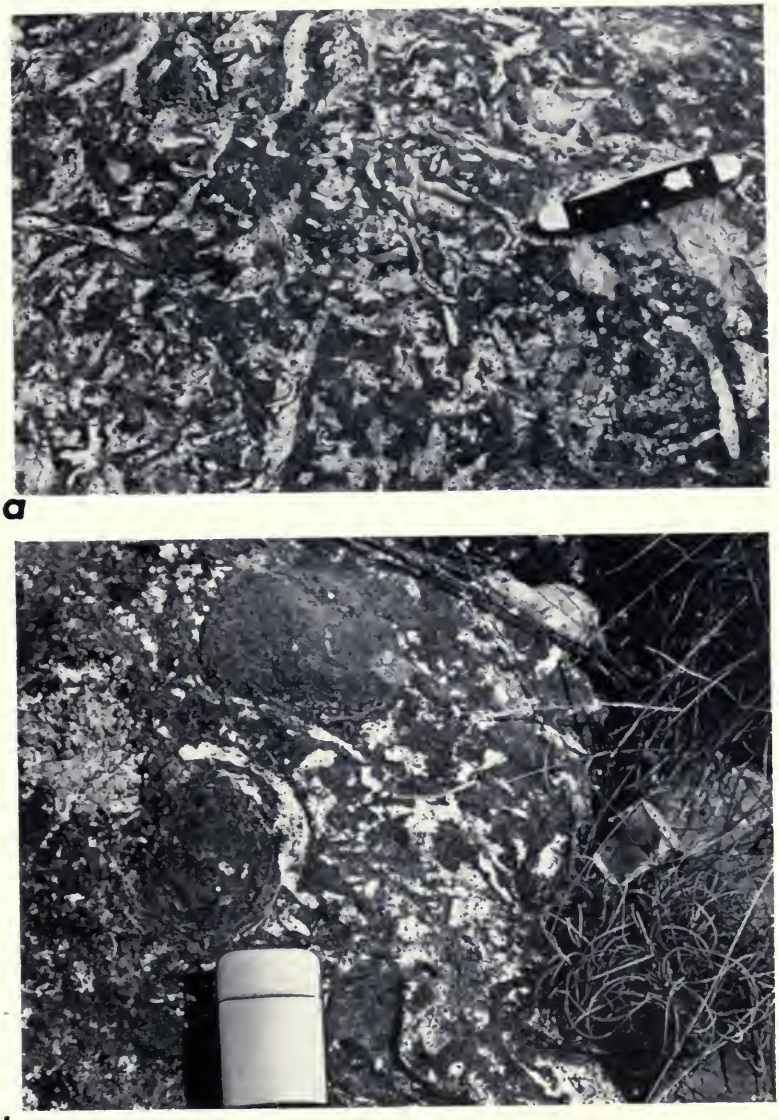


FIG. 70. Close-up outcrop photographs taken of the surface in the zone of abundant *Archaeoscyphia* located 100 ft. above the base of the Kindblade Formation at the Mill Creek section. (a) Surface of typical moundrock showing abundant organism burrows; the burrows (white) are incipiently silicified. (b) Surface showing two small algal structures with burrows around the algal "heads" and a chert replaced fragment of *Archaeoscyphia*.

FIG. 71. Outcrop photographs taken at a stratigraphic interval 440 ft. above the base of the Kindblade Formation at the Mill Creek section. **(a)** Thin-bedded Kindblade Formation limestone adjacent to the mounds in the zone of abundant *Calathium;* thin-section examination of this rock shows it to be a mudstone with rare organism burrows containing some fecal pellets. **(b)** Mound surface with scattered chert replaced fragments of *Archaeoscyphia.*

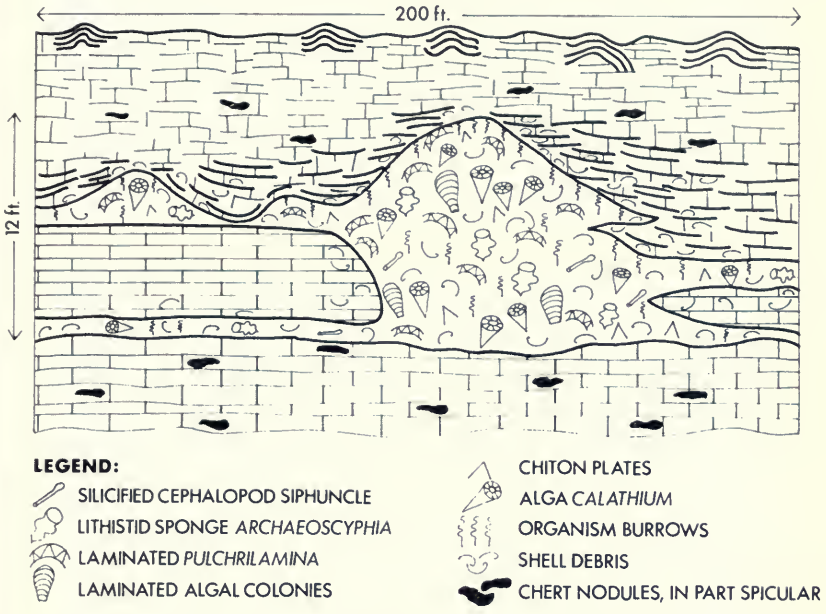



FIG. 72. Schematic diagram of an organic buildup in zone of abundant *Calathium* exposed at the Mill Creek section, Arbuckle Mountains, southern Oklahoma.

imately 420 to 445 ft. above the base of the Kindblade Formation (fig. 31). Exposed moundrock containing concentrations of silicified *Calathium* with common calcified archaeoscyphid sponges is rather common throughout this interval. Usually the organic buildups are less than 5 ft. in height and of variable width, some having a diameter of 10 ft. The mounds are separated from one another by mound-shed intermound skeletal debris, or by well-defined channels that are up to 1 ft. in width.

Petrologically, the moundrock of this interval can be classified as an intraclastic skeletal wackestone, with remains of the receptaculitid alga *Calathium* as the dominant biotic component (fig. 67). No distinctive *Pulchrilamina* was observed, and little indication of encrusting and binding renalcid colonies was seen within this entire interval. Hence, no boundstone was observed. Only a few clotted algal? laminations and *Girvanella* tubules were noted. The rock is burrowed. Large orospirid-type gastropods (up to 1½ in. in diameter) were identified. Other skeletal debris included sponge spicules, pelmatozoans, and trilobite fragments.

Formic acid residues of moundrock from this interval have yield-

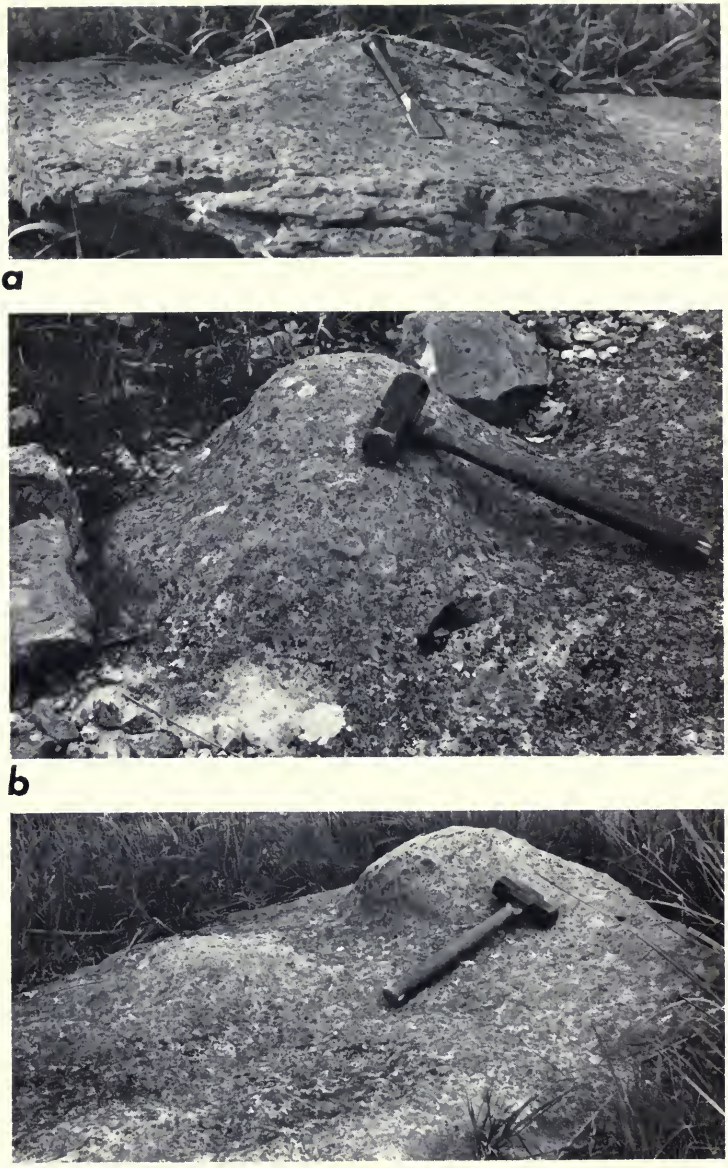



FIG. 73. Small algal mounds ("miniherms") on the bedding plane surface of the bed overlying the major zone of abundant *Calathium*, 450 ft. above the base of the Kindblade Formation at the Mill Creek section. The surfaces of the mounds contain conspicuous organism burrows, scattered chert replaced *Archaeoscyphia* and silicified *Calathium*. The mounds are composed of laminated algal structures with common *Girvanella* tubules along the laminae; chisel, 7 in. long; hammer, 15 in. long.

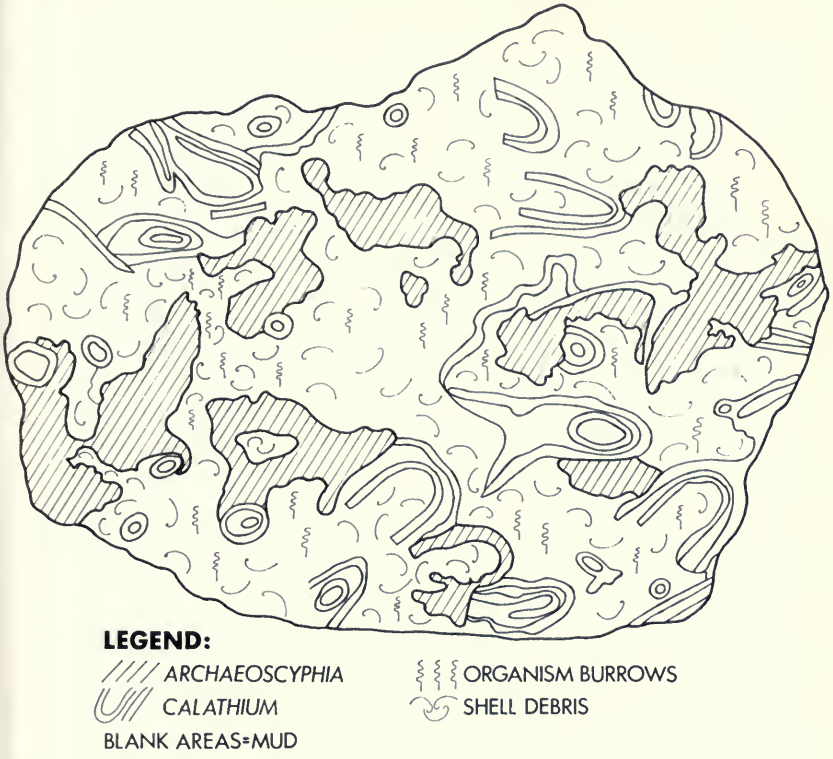



FIG. 74. Overlay of a polished slab of Kindblade moundrock from the upper mound interval at the Mill Creek section, Arbuckle Mountains, southern Oklahoma.

ed some sponge spicules and simple distacodid conodonts. The conodonts are listed on Table 4.

The intermound-channel rock in this upper mound interval can be classified as an intraclastic grainstone. The intraclasts are of irregular shape and some contain many *Girvanella* tubules. Trilobite fragments are particularly abundant in the channel rock.

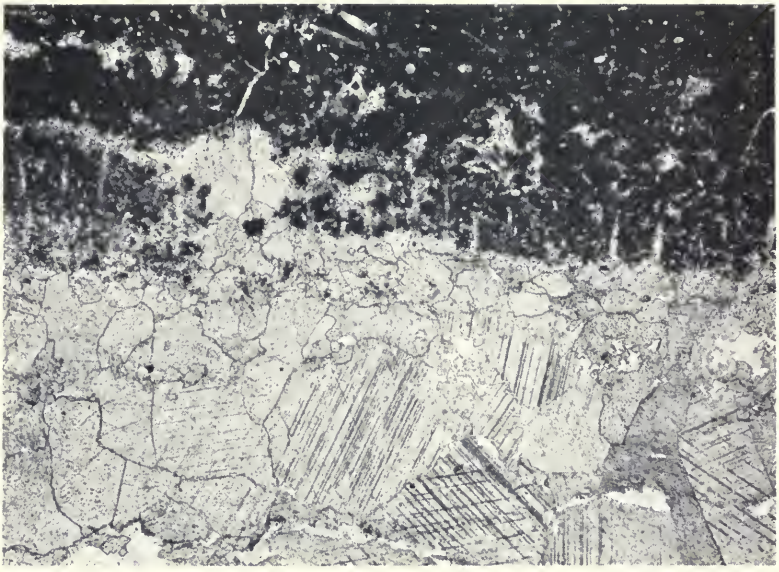
**Mill Creek Section.**—The Mill Creek section is located in the northern Tishomingo Anticline in Murray County, and is plotted as section C on Figure 30. At this location both the lower and upper mound intervals are well exposed (fig. 31). However, at a stratigraphic interval 25 ft. above the base of the Kindblade Formation numerous small buildups are exposed on the bedding plane surfaces (fig. 68a). These "mound" structures are less than 1 ft. high and have a diameter of approximately 3 ft. A few silicified *Ar-*

*chaeoscyphia* are present on the "mound" surfaces, but for the most part the rock appears to have a clastic texture. In fact, thin-section examination of this horizon demonstrates that these "mound-like" structures are probably erosional sculptured features composed of intraclastic grainstone-packstone (fig. 68b). Superficially, they appear to be small organic buildups, but they are composed of clastic debris consisting of algal? fragments (laminated structures containing rare solenoporid-type algal fragments), and debris of pelmatozoans, gastropods, and trilobites. The dominant intraclasts are irregularly-shaped, and some show *in situ* brecciation. These "pseudo-mounds" are abundant at this stratigraphic interval.

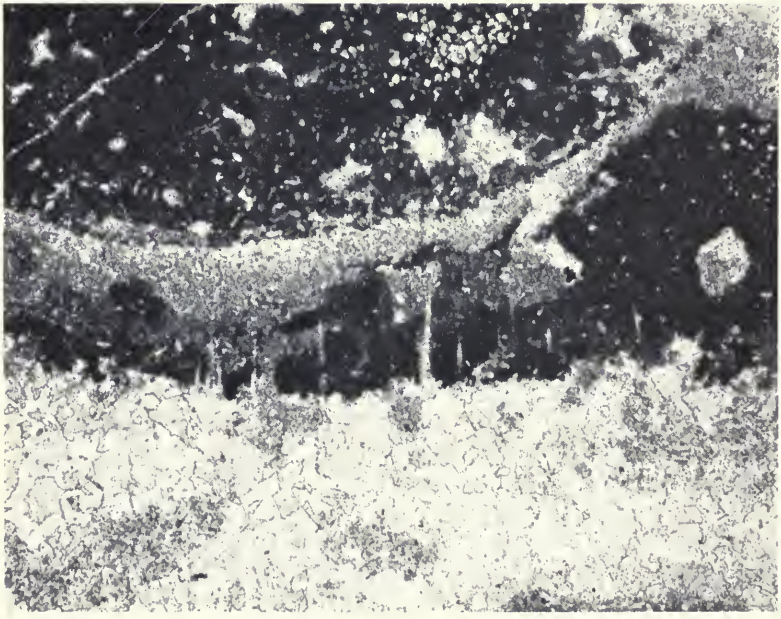
The lower mound interval is well developed and is one of the thickest zones of abundant *Archaeoscyphia* found in Oklahoma. Stratigraphically, this interval ranges from approximately 80 to 175 ft. above the base of the Kindblade Formation. Within this interval, a number of biostromal horizons laterally grade into relatively small algal-sponge buildups. All of the organic buildups are less than 5 ft. high and have variable diameters, ranging up to a maximum of 12 ft. Morphologically and faunally, these organic buildups are similar to those described above from the same interval at the Joins Ranch (fig. 52) and Southern Tishomingo Anticline sections. The lithistid sponge *Archaeoscyphia annulata* Cullison is dominant and is closely associated with laminated stromatolitic colonies. Most of the archaeoscyphid specimens are silicified (fig. 69a), although polished slabs from this interval also indicate common calcified *Archaeoscyphia.* Specimens of *Archaeoscyphia* range up to 8 in. in length and have a diameter of 2½ in. Specimens of the receptaculitid alga *Calathium* are relatively rare, although an occasional silicified specimen may be seen on the mound surface (fig. 69b). The surfaces of the organic buildups are covered with organism burrows, most of which are infilled with white-colored silicified material (fig. 70a). Associated with the burrows are small, partially silicified, algal heads (fig. 70b). When the heads are broken open they are seen to be composed of laminated stromatolitic material; in thin-section, some of the laminae carry *Girvanella* tubules. Silicified endosiphun-

*Opposite:*

FIG. 75. Thin-section photomicrograph ( × 3) of moundrock from the zone of abundant *Calathium* located 445 ft. above the base of the Kindblade Formation at the Mill Creek section. Note the abundance of the receptaculitid alga *Calathium* with its distinctive wall structure. Scattered skeletal debris, along with organism burrows are also present in this photomicrograph.



a



b

cular structures identified as *McQueenoceras* also occur on these mounds.

Petrologically, the moundrock from this interval is highly burrowed, intraclastic, skeletal wackestone. In some instances where algal material binds the grains and rock matrix, and when encrusting *Renalcis* colonies bind archaeoscyphid sponges together, the moundrock can be referred to as a boundstone. Other skeletal material common in moundrock thin-sections includes sponge spicules and debris of pelmatozoans, brachiopods, gastropods, cephalopods, and trilobites.

Acid etching of moundrock yielded an abundant assemblage of monaxon, lithistid, octactine, and triactine sponge spicules, along with distacodid conodonts. The conodonts retrieved from this interval are listed on Table 3.

Here also at an approximate stratigraphic interval 770 ft. below the base of the Kindblade Formation, in a 1 ft. horizon within the Cool Creek Formation, is a layer of poorly preserved chert replaced fragments of the lithistid sponge *Archaeoscyphia*. This zone is similar to that noted above at the Joins Ranch section and in coeval zones in the Ellenburger of central Texas and the El Paso of West Texas.

The upper mound interval is well exposed on a "rock prairie" in the northern part of the Tishomingo anticlinal horst, in the central area of the Arbuckle Mountains. The strata dips up to 11 deg. toward the west. The best exposures of organic buildups occur in and around a series of collapsed sinks, and beyond the sinks on each side for a distance of approximately 200 ft. Stratigraphically, the upper mound interval ranges from approximately 425 to 445 ft. above the base of the Kindblade Formation. Within this interval, mound-intermound relationships are well developed. The organic buildups are up to 12 ft. in height and reach a width of 50 ft. Surfaces of the buildups are massive, light-colored limestone and contain abundant organisms representing silicified specimens of all of

*Opposite:*

FIG. 76. Thin-section photomicrographs ( × 20) of the colonial laminated organism *Pulchrilamina spinosa* Toomey & Ham from a mound horizon located stratigraphically 450 ft. above the base of the Kindblade Formation at the Mill Creek section. (a,b) Individual laminae with the characteristic but irregularly distributed spines on the upper surface; interlaminal areas contain much mud usually, and threads of the blue green alga *Girvanella* (not seen at this magnification) entwining the spines and throughout the mud matrix.

the dominant biotic components: laminated algal colonies, *Calathium, Archaeoscyphia* (fig. 71b), and *Pulchrilamina.* In addition, subordinate numbers of silicified chiton plates and cephalopod siphuncles also occur. Beds abutting against the mound show slight dips and some broken mound-derived skeletal debris extends outward for a very short distance from the mounds. The mound surfaces, besides containing abundant silicified organism remains, also contain conspicuous areas of organism burrows.

Laterally adjacent to the organic buildups are dark-colored, thin beds of unfossiliferous mudstones (fig. 71a). Some organism burrows with contained fecal pellets are the only organism traces found in these intermound beds.

The outcrop relationships of the mound-intermound areas at the Mill Creek section are shown schematically on Figure 72.

Of special interest at this section is the occurrence of many small algal mounds ("miniherms") on the bedding plane surface of a prominent bed overlying the major zone of abundant *Calathium* 450 ft. above the base of the Kindblade Formation. The mounds are small, about 1 ft. high and up to 14 in. in diameter. They are shown schematically at the top of Figure 72, and illustrated on Figure 73. Characteristically, the surfaces of the mounds are covered with organism burrows that are infilled with light-gray siliceous material. A few scattered, silicified *Calathium* and *Archaeoscyphia* specimens have also been observed. When broken open, the heads are found to be composed of laminated stromatolitic algal material. Thin-section examination shows that the stromatolite laminae contain entwined tubules of the blue-green alga *Girvanella.* Small "miniherms" of this type are rather common organic structures found at a number of locations at many horizons within the lower Kindblade Formation.

Megafossils, for the most part silicified, are abundant and varied within the major organic buildup interval and consist of:

(1) *Calathium* (one very large though incomplete specimen has a diameter of 5 in., and the central portion is filled with clusters of orospirid-type gastropods);
(2) *Archaeoscyphia annulata* Cullison up to 8 in. in length with a maximum diameter of 1½ in.;
(3) the orthid brachiopod *Finkelnburgia crassicostata* Cooper;
(4) high-spired gastropods (cf. *Hormotoma);*
(5) cephalopod siphuncles *(McQueenoceras);*

(6) a varied chiton fauna representing four genera and seven species as reported in Smith & Toomey (1964) and including: *Paleochiton kindbladensis, Ivoechiton oklahomensis, I.* sp., *I. calathicolus, Eochiton arbucklensis, Gotlandochiton hami,* and *G.* sp.

The abundance of organisms seen within the organic buildup interval is well demonstrated in Figure 74. Here, an overlay of a polished slab of moundrock was prepared to show the relative abundance of both *Calathium* and *Archaeoscyphia.*

Petrologically, the moundrock of the upper mound interval can be classified as a burrowed, intraclastic, skeletal wackestone. Typical moundrock is shown in the photomicrograph in Figure 75. The rock has a mud matrix and is dominated by abundant specimens of the receptaculitid alga *Calathium.* Usually, the lithistid sponge *Archaeoscyphia* is quite common, although it is not seen in this photomicrograph. Other skeletal debris includes tubules of *Girvanella,* sponge and calathid spicules, and fragments of pelmatozoans, brachiopods, gastropods, chitons, and trilobites. Trilobite remains are especially common in some organic buildups. A few specimens of *Archaeoscyphia* were observed with encrustations of *Renalcis* on their outer wall; no binding by *Renalcis* was seen. Good specimens of the laminated and encrusting organism *Pulchrilamina spinosa* Toomey & Ham are also common in some moundrocks. Thin-section photomicrographs of this organism are shown in Figure 76. Specimens of *Pulchrilamina* found at this locality are usually coarsely chertified, but preparation of numerous thin-sections from one organic buildup discovered a pocket in which calcified specimens of *Pulchrilamina* were present. These specimens show the characteristic, but irregularly distributed spines on the upper surfaces of the laminae. Inter-laminae areas are usually mud-filled, but contain tubules of the blue-green alga *Girvanella.*

Formic acid etching of moundrock from this interval yielded rare-to-common monaxon, lithistid, octactine, and triactine sponge spicules and distocodid conodonts. The conodonts are listed on Table 4.

**Occurrence of *Ceratopea* in Oklahoma Mound Interval.**—As noted under the discussion of the McKelligon Canyon organic buildups, the gastropod *Ceratopea* is best known from its massive operculum, and is an important fossil for differentiating Lower Ordovician stratigraphic zones.

Silicified specimens of *Ceratopea* have been found in the lower Kindblade Formation of both the Wichita and Arbuckle Mountains. The *Ceratopea* occurrences from the Arbuckle Mountains have been documented by Yochelson (1973) on the basis of collections made earlier by the late Bill Ham. This same *Ceratopea* sequence is also present in the Wichita Mountains, and, as in the Arbuckle Mountains, no specimens of *Ceratopea* have been found on organic buildups. However, the zonation found at both locations indicates that the upper mound interval is stratigraphically within the limits of the Honeycut Formation (Ellenburger Group) of central Texas, but is slightly higher than the main organic buildup horizons in the southern Franklin Mountains at El Paso, West Texas. It lies a little above the zones of *Ceratopea capuliformis* Oder and *C. incurvata* Yochelson & Bridge and just below the next overlying *Ceratopea* zone, that is, the zone of *C. tennesseensis* Oder, as is shown in Yochelson & Bridge (1957). The lower mound interval lies within the zones of *Ceratopea capuliformis* Oder and *C. incurvata* Yochelson & Bridge and is more closely related to the McKelligon Canyon Formation organic buildups.

**Summary.**—Organic buildups are present in the lower Kindblade Formation in three sections from the Wichita Mountains of southwestern Oklahoma, and in four sections from the Arbuckle Mountains of southern Oklahoma. They occur in two distinctive stratigraphic intervals herein designated the lower and upper mound intervals.

The lower mound interval ranges in thickness from 10 to 95 ft., with an average thickness of 65 ft. All occurrences of the lower mound interval begin within the lowermost 100 ft. of the Kindblade Formation. The moundrock is light-colored, massive, unbedded, and characterized by a high concentration of *in situ* fossil organisms. The organic buildups are composed principally of stromatolitic algae and lithistid sponges. The dominant organism is the sponge *Archaeoscyphia annulata* Cullison, mainly found as chert replacements. Laminated, stromatolitic algal colonies are also abundant and organic debris is entwined within algal swirls. Accessory organisms include *problematica* (especially the colonial encrusting form *Renalcis*), other algae (i.e., the receptaculitid alga *Calathium*), pelmatozoans, brachiopods, gastropods, cephalopods, trilobites, and conodonts. Individual organic buildups are usually less than 10 ft. in height, although one well exposed organic buildup at the Kindblade Ranch section has a height of 28 ft. and a width of over 100 ft.

The organic buildups are usually encased in dark-colored, thin-bedded sediments of various types, although pelletal mudstone is a fairly common intermound rock type. The boundary of the buildup is generally a sharply defined line marking the contact between light-colored, massive, unbedded moundrock and darker, thin-bedded, non-moundrock. Talus derived from the organic buildup is conspicuously absent or only poorly developed.

Petrologically, the lower interval moundrock can be described as an intraclastic, burrowed, skeletal wackestone. In some instances, when much stromatolitic algal material is present, and indigenous skeletal debris is entrapped within algal swirls, the moundrock can be classified as a boundstone.

No erosional channels cut the surface of the organic buildups within this interval, and there is no evidence of any periods of subaerial exposure. Accordingly, it is believed that these organic buildups developed entirely within shallow marine subtidal waters. The best developed exposures for this interval are found at the Kindblade Ranch section in the Wichita Mountains, and the Mill Creek section in the Arbuckle Mountains.

The upper mound interval ranges in thickness from 25 to 65 ft., with an average of 40 ft. All occurrences of the upper mound interval begin at a stratigraphic horizon approximately 400 ft. above the base of the Kindblade Formation. The moundrock is massive, unbedded, and distinguished by clustered concentrations of *in situ* organisms. The organic buildups are composed principally of the receptaculitid alga *Calathium,* stromatolitic algae, the lithistid sponge *Archaeoscyphia annulata* Cullison, and the problematical laminated colonial organism *Pulchrilamina spinosa* Toomey & Ham. The dominant organic buildup biotic component is *Calathium.* All of the above organisms may be silicified.

Accessory organisms include: *problematica* (of which the colonial, encrusting, and binding duo *Renalcis-Epiphyton* are important), other algae, bryozoans, pelmatozoans, brachiopods, gastropods, chitons, cephalopods, trilobites, and conodonts. Individual organic buildups are less than 10 ft. in height, although the largest Kindblade buildup found to date occurs in this interval and measures 65 ft. in height and up to 175 ft. in length. There is abrupt contact between the organic buildups and the darker-colored, thin-bedded limemuds carrying only sparse organism burrows. This boundary between moundrock and non-mound and intermound rock is very

sharp and no mound-derived talus is present. Generally, there is no intermound-mound overlap or appreciable upturning of the offmound-intermound beds. However, in a few instances the offmound beds slope upward over the side of the buildup with a dip of about 10 deg. through a vertical interval of about 1 ft.

Petrologically, the moundrock of the upper mound interval can be described as an intraclastic, burrowed skeletal wackestone. When much stromatolitic algal material and *Pulchrilamina* occur, either separately or together with *Renalcis-Epiphyton* binding and encrusting other skeletal grains, the moundrock can be considered as a true boundstone.

Erosional channels are a distinctive feature of the upper mound interval. They separate many of the organic buildups, and are usually about 1 ft. in width forming a characteristic anastomizing pattern around the structures. Petrologically, the channel rock can be classified as a packstone to grainstone composed chiefly of well-rounded intraclasts associated with much abraded mound-shed skeletal debris. Evidence of subaerial exposure at the tops of these organic buildups has not been observed. Taking into consideration the characteristic mound structure, and associated erosional surge channels, these organic buildups must have grown in shallow, well-agitated subtidal waters. The best developed exposures for this interval occur at the Longhorn Mountain section in the Wichita Mountains, and at both the Joins Ranch and Mill Creek sections in the Arbuckle Mountains.

In addition to the organic buildups noted above, small structures herein termed "miniherms" are conspicuous organic features in many horizons throughout the lower Kindblade Formation. These mounds are usually only 1 ft. in height and have an average diameter of 14 in. They are found in both the Wichita Mountains and the Arbuckle Mountains, and are composed chiefly of laminated stromatolitic material with only rare occurrences of *Archaeoscyphia* and *Calathium* noted in any of these miniherms. Most commonly, they are well exposed on bedding plane surfaces. Petrologically they can be described as algal boundstones. The surfaces of these structures are characteristically covered with organism trails and burrows. Best exposures of these miniherms were noted in the Arbuckle Mountains at the Mill Creek and Highway 77 sections.

It is thought that all of the above Kindblade organic buildups grew in relatively shallow subtidal waters, and that these structures probably did not attain any great height while growing. At any one

time the organic buildups stood no more than 5 to 10 ft. above the surrounding seafloor. In essence, these were low relief domical features which offered refuge and sanctuary to a unique Lower Paleozoic clustered biota dominated by algae and sponges.

**Value and Stratigraphic Occurrence of Certain Arbuckle Megafossils.**— The late Dr. W.E. Ham began his detailed studies on the stratigraphy of the Wichita and Arbuckle Mountains in the early 1940's. At the time of his death in 1970, much of the stratigraphic faunal data was still in note form and had not been published. Since both of us had done additional megafossil collecting for this study, it was decided to put together what available faunal data had been gathered relative to that portion of the Lower Ordovician sequence with which we were most familiar, specifically, the upper Cool Creek and lower Kindblade Formations. Accordingly, Figure 77 is a stratigraphic range chart of the most common megafossils occurring within this Lower Ordovician interval.

Good, usable megafossils in the Lower Ordovician sequence are indeed rare. Careful, bed-by-bed examination and collecting over many years has yielded 21 forms found to be of stratigraphic value. All of these are fossils that readily lend themselves to silicification, and are usually found as concentrations of silicified replacements. These concentrations generally occur fortuitously, and usually on bedding plane surfaces. The most common megafossils, in order of abundance, are: gastropods (including *Ceratopea*), orthid brachiopods, lithistid sponges, receptaculitid algae, cephalopod siphuncles, *incertae sedis (Pulchrilamina)*, and chiton plates. All occur within strictly defined stratigraphic intervals, as presently known.

The gastropod operculae grouped under the genus *Ceratopea* are perhaps the best stratigraphic indices for a definitive sequence. *C. capuliformis-incurvata-corniformis-keithi-tennesseensis* has previously been shown to have meaningful stratigraphic age value (Yochelson & Bridge, 1957; Yochelson, 1973). Other gastropods like *Lecanospira* sp. occur abundantly in a zone from 200 to 320 ft. below the top of the Cool Creek Formation. Species of *Orospira* are very abundant at 340 ft. below the top of the Kindblade Formation and continue down at least 260 ft. above the base of the formation. The high-spired gastropod *Hormotoma* spp. has a much shorter stratigraphic range; it is dominant at 180 ft. above the base of the Kindblade, although both forms occur within the lower mound interval. *Hormotoma* has been found beginning at an interval 640 ft. below the top of the Kindblade, but we suspect that this form

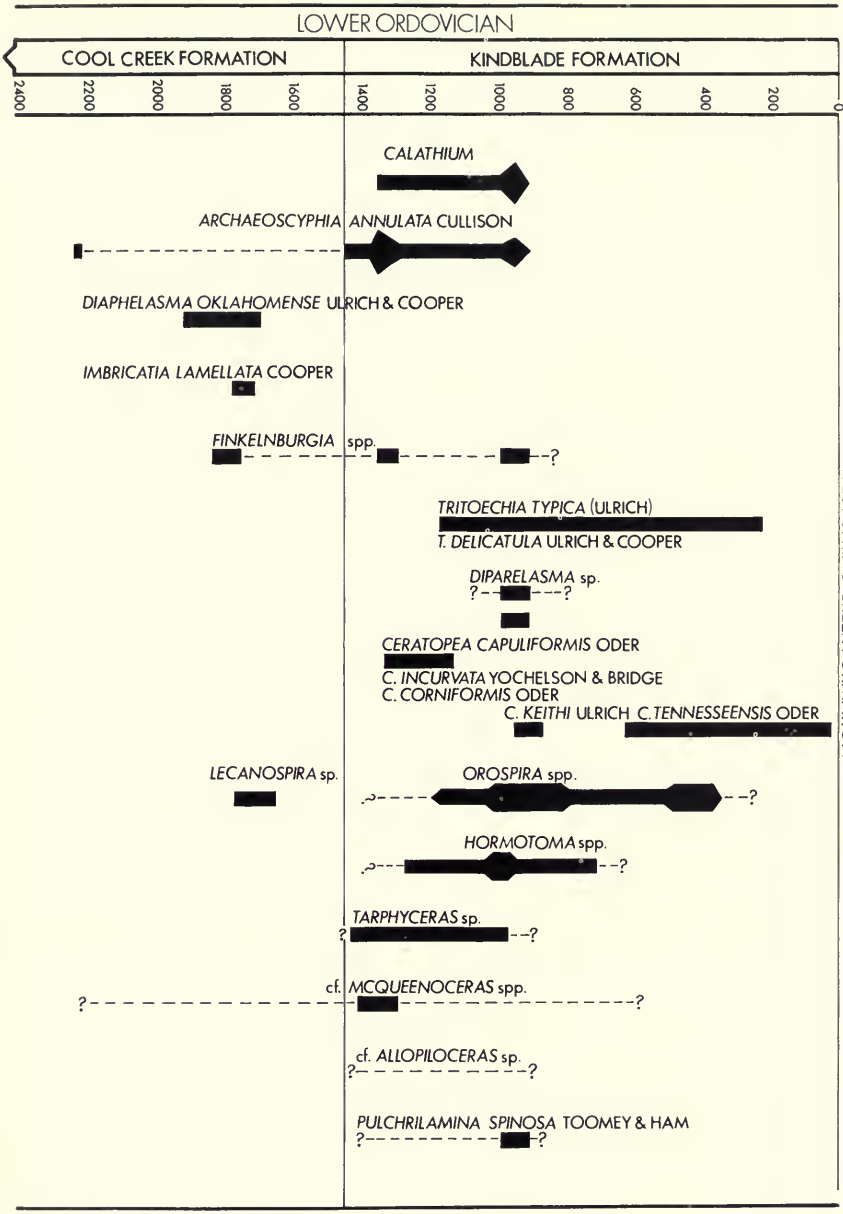



FIG. 77. Stratigraphic range chart of most common fossils occurring in the Kindblade Formation and upper part of Cool Creek Formation in Wichita and Arbuckle Mountains of southern Oklahoma.

ranges much higher in the formation.

The lithistid sponge *Archaeoscyphia* occurs within a very thin stratigraphic horizon approximately 770 ft. below the top of the Cool Creek Formation. This form is not seen again until the very base of the Kindblade Formation. It ranges upward in the Kindblade for approximately 550 ft. above the base. The large receptaculitid alga *Calathium* is a lower Kindblade guide fossil, occurring only within the lower most 550 ft. of the formation, and is abundantly concentrated within an organic buildup interval that averages 40 ft. in thickness.

Various small orthid brachiopods, like *Diaphelasma oklahomense* Ulrich & Cooper, *Imbricatia lamellata* Cooper, and an indeterminate species of *Finkelnburgia*, occur in the upper part of the Cook Creek Formation. Other species of *Finkelnburgia*, primarily *F. crassicostata* Cooper, occur on the organic buildups and within stratigraphic units of the major mound intervals. The brachiopods *Tritoechia typica* (Ulrich) and *T. delicatula* Ulrich & Cooper are good stratigraphic markers that are relatively common beginning at 220 ft. down from the top of the Kindblade Formation all the way to 1,180 ft. below the top of the formation. However, both these forms have not been identified on any of the organic buildups. The brachiopod *Diparelasma* sp. has a very restricted stratigraphic range, but occurs only rarely.

Of the cephalopods, slender silicified endosiphuncular structures referred to the genus *McQueenoceras* are most abundant. These characteristic megafossils range from the middle of the Cool Creek Formation to the middle of the Kindblade Formation, but they are most conspicuous within the interval from 40 to 160 ft. above the base of the Kindblade Formation. They are concentrated on many of the organic buildups within the lower mound interval. The coiled nautiloid *Tarphyceras* sp. cf. *T. chadwickense* Ulrich, Foerste, Miller & Furnish, is restricted to the lower Kindblade, and is commonly found on many organic buildups of both lower and upper mound intervals. The siphuncle referred under the genus *Allopiloceras?* sp. also appears to be restricted to the lower Kindblade interval, but occurs only rarely.

The laminated, encrusting *problematica Pulchrilamina spinosa* Toomey & Ham appears to be confined to the lower 550 ft. of the Kindblade Formation. It occurs only sporadically within the lower mound interval, but reaches its fullest development within the up-

per mound interval, generally 400 to 450 ft. above the base of the formation.

Stratigraphic correlation and tie-in of the Oklahoma and Texas sections to those of the Great Basin composite western United States succession, developed by Ross (1951) and Hintze (1951), is given in Figure 3. This correlation relates trilobite faunal zones of the Garden City-Ibex areas to the Lower Ordovician interval of Texas and Oklahoma.

## COMPARISON WITH LOWER ORDOVICIAN ORGANIC BUILDUPS IN OTHER REGIONS

Other than those organic buildups herein reported from Oklahoma and Texas, there are few additional Lower Ordovician occurrences described from North America. It is interesting to note that in the Lower Ordovician of Siberia the organic buildups as described by Miagkova (1973) appear to be very similar to our structures, particularly their biohermal organic components composed mainly of *Soanites* (our *Calathium*). Only three North American areas have been mentioned or studied in some detail. These are: (1) western Utah, (2) western Canada, and (3) western Newfoundland. Of these, the organic buildups from western Utah are best known.

**Western Utah.**—Rigby (1965, 1971) reported on Lower Ordovician organic buildups occurring in the Pogonip Group (lower 700 ft. of Fillmore Limestone) from the Confusion Range of western Utah. Rigby noted that development and replacement of organism communities was well demonstrated within this interval. In the earliest recognizable Lower Ordovician organic buildups, he found that lithistid sponges played a minor role and that stromatolitic algae were dominant. Higher in the sequence, four buildup horizons are well developed, and consist of buildups up to 30 ft. in diameter that are composed of stromatolitic algal heads with abundant lithistid sponges. The sponges are indigenous to the organic buildups, but also occur as fragmented specimens in the thin-bedded limestone associated with the mounds.

Lithistid sponges are also dominant in the upper two organic buildup horizons, and here they occur with abundant specimens of the receptaculitid alga *Calathium.* Rigby (1971, p. 1,376) commented that the organic buildups of the Lower Ordovician portion of the Pogonip Group are relatively small, paleontologically simple structures in which deeply conical lithistid sponges are intimately associated with stromatolitic algae. These sponges are up to 8 in. in

height and 5 in. in diameter. Biotas from younger organic buildups are still dominated by lithistid sponges, but broader, low, conical forms up to 20 in. in diameter, along with subcylindrical and annulated forms such as *Archaeoscyphia* and others, are also abundant on these younger algal-sponge buildups.

Roberts (1967) reported on Lower Ordovician organic buildups from the same general region of southwestern Utah. He noted that the buildups are primarily algal-sponge associations that exhibit a considerable range of variation with respect to kinds and numbers of biotic constituents. He observed that, in general, sponges function as frame-builders, whereas algae function as binders. The main accessory organisms are brachiopods, cephalopods, and trilobites. Study of the petrology and sedimentary structures within the organic buildup intervals indicates a very shallow water paleoenvironmental setting for buildup growth and development.

Church (1974) presented a detailed study of the Lower Ordovician organic buildups from the Fillmore Formation exposed in the southern House Range and the Yersin Hills of western Utah. These small, linear organic buildups occur in the lower part of the Fillmore Formation (almost 600 ft. above the base of the formation) in the slope-forming shaly siltstone member. The buildups outcrop for approximately 1 mile along the strike, and a total of 57 structures were studied. They are located on the eastern margin of the Lower Ordovician miogeosyncline, and probably grew in shallow tropical seas that are believed to have covered much of western Utah at this time. These small organic buildups are up to 4½ ft. in height, 9 ft. in width, and 90 ft. in length. Church (1974, p. 46) refers to the buildups as being "sausage-shaped." The mounds are separated laterally at regular intervals of about 30 ft. and occur as discontinuous northeast-trending parallel structures. The buildups diminish in size in a westward direction and laterally grade into biostromal units.

The moundrock is a burrowed, intraclastic, skeletal wackestone to boundstone composed of stromatolitic algae, receptaculitid algae *(Calathium),* lithistid sponges *(Archaeoscyphia* and others), pelmatozoans, brachiopods *(Apheoorthis* and *Glyptotrophia),* gastropods, cephalopods, and trilobites. Stromatolitic algal growths surround and bind a good portion of the buildups skeletal constituents. Of special note is the occurrence within the buildups of a problematical encrusting and binding micro-organism identified

as *Tubiphytes obscurus* (Maslov). This problematical form is more common in Late Paleozoic organic buildups, and this occurrence marks the first record of *Tubiphytes* in rocks of Lower Paleozoic age. Simple distacodid conodonts have also been retrieved from the moundrock and identified by Ethington. These indicate the age comparable or a little younger than the conodonts from the McKelligon Canyon organic buildups in West Texas.

Intermound rock consists of intraclastic, skeletal packstones to grainstones. Some intraformational conglomerate is also present, and a thin layer serves as the foundational unit upon which the organic buildups were initiated. The principal biotic components of the intermound rock include skeletal debris from algae, pelmatozoans, and trilobites. Abraded fragments of *Archaeoscyphia* and *Calathium* occur only in the rock immediately adjacent to the organic buildups. Some bedding plane surfaces of the intermound rock are ripple marked. Lateral contact between the mound and intermound rock is sharp, and as Church's diagram (fig. 4, p. 49) indicates, there is only a slight upbending of the intermound beds at the immediate contact. Blocks of moundrock, up to 1 ft. in height, that have fallen from the buildup during deposition, also have sharp contact with the surrounding intermound rock and indicate the relative firmness of the sediment during growth.

Church (1974, p. 60) has observed a successional sequence of mound growth indicating a three-phase development. A pioneer community of stromatolitic algae stabilized the foundation and initiated the early growth stage. This was followed by development of a more mature biotic community in which algae, sponges, pelmatozoans, brachiopods, gastropods, cephalopods, and trilobites expanded their niche role within the buildup. The culminating phase is the development of the climax community which is dominated by the receptaculitid alga *Calathium.* With its well-developed root system, this form firmly attached itself to surrounding objects and projected upward to act as a baffle along with the sponges, trapping sediment and providing a favorable environment for exploitation. Mound growth apparently ceased with a change in sedimentation and the deposition of the overlying dark gray calcareous shale.

**Western Canada.**— Rigby (1965) measured a thick section (4,026 ft.) of Cambro-Ordovician sediments near the Columbia Icefields section at Jasper National Park, Alberta, western Canada. In the Lower Ordovician Sarbach Formation he found algal-sponge

buildups in a stratigraphic interval 125 to 189 ft. above the base of the formation.

He noted (p. 172) that several small algal-sponge buildups occur in unit 30 of the lower portion of the Sarbach Formation, and that individual buildups range up to 6 ft. in diameter, and are blue-gray in color. These organic buildups are only exposed in cross-section, as they wedge in and out between less massively bedded clastic limestones. The measured section description of this unit (p. 181) notes that stromatolitic algal colonies *("Collenia")* up to 2 ft. in height are common in the moundrock.

Individual organisms are not conspicuous on outcrop surface, but the moundrock fabric is clearly seen on polished slabs and in thin-sections. Only then was the overall abundance of algae and sponges observed. Lithistid anthaspidellid sponges are abundant and only these occur in the organic buildups.

Rigby reports that the massive organic buildups are surrounded by thin-bedded medium to dark-gray skeletal limestones.

**Western Newfoundland.**— Stevens & James (1976) have given a preliminary description of Lower Ordovician sponge organic buildups from a portion of the St. George Group sediments outcropping in western Newfoundland. In an interval of sediments they regard as representing a typical subtidal facies, they have discovered an organic buildup complex.

The buildups consist of a series of coalescing rounded "heads" up to 6 ft. in diameter and 3 ft. in height. Stevens & James note that each "head" is composed of a series of upward opening cups with their walls dolomitized and the interiors filled with dark, burrowed mudstone. Surrounding the closely-packed "heads" are distinctive packstones and grainstones that are also burrowed and contain algally coated-grains (oncolites). The dominant large organism on these organic buildups is a large, solitary, siliceous sponge, tentatively identified as *Archaeoscyphia* sp. In one outcrop area the interval containing organic buildups is more than 210 ft. in thickness, but tracing of beds indicates a thinning of this interval to less than 60 ft.

A personal communication from James, accompanied by outcrop photographs, unmistakeably demonstrates the major contribution played by lithistid sponges and *Calathium* in the construction of these organic buildups. One of the photographs clearly shows distinct annulations of the sponge wall suggesting that this species

is probably a typical *Archaeoscyphia annulata* Cullison. Other lithistid sponges also appear to make up the buildup assemblage. Formal description of these significant organic buildups will be of interest.

**Summary.**—In spite of rather limited field data on only a few Lower Ordovician sections containing organic buildups. we can make some comparisons and generalizations. First, these organic structures are biotically relatively simple. That is, their organism assemblages are limited to only a few characteristic biotic components. These are: (1) stromatolitic algae, (2) lithistid sponges, and (3) various *problematica* (questionable algae, and in the West Texas-Oklahoma occurrences, a possible ancestral coelenterate). Accessory organisms enter the mound assemblage and diversify only after the buildup has been initially developed. These accessories are consistently made up of pelmatozoans, simple orthid brachiopods, various gastropods, cephalopods, and trilobites. When the organic buildups show a vertical ecologic zonation, this appears to be simply an organism response to increasingly shallower environments. In essence, a response to changing physical conditions. When this is carried to completion we see the development of a distinctive organism climax community. In the organic buildups of the McKelligon Canyon Formation the probable coelenterate *Pulchrilamina* dominates the climax assemblage, whereas in the western Utah and Newfoundland receptaculitid algae *(Calathium)* firmly bind sponges and other skeletal debris into a cohesive structural unit marking its climax. Conversely, if the depositional setting of the mound interval remains only within the subtidal regime we do not see an obvious vertical ecologic zonation, i.e., the Kindblade organic buildups of southern and southwestern Oklahoma. However, we still find indications of shallow water environments such as the erosional channels surrounding many of these buildups.

Second, most Lower Ordovician organic buildups are relatively small-scaled structures. At most localities the average size is less than 10 ft. in height and up to 6 ft. in diameter. Larger buildups do occur, i.e., Longhorn Mountain buildup in the Wichita Mountains, Oklahoma, but these are exceptional.

Third, we can describe all Lower Ordovician moundrock as light-colored and massive, and containing significant concentrations of *in situ* organisms. Petrologically, moundrock is burrowed, intraclastic, skeletal wackestone. Where stromatolitic algal material dominates,

and organisms become entwined within the algal laminations, the moundrock can be considered as a true boundstone. The climax communities in both the Texas-Oklahoma occurrences and the western Utah locations are distinctive boundstones. In contrast, the intermound rock is generally dark-colored and thin-bedded, and in some instances the intermound rock does not contain any mound-shed skeletal debris and can be classified as a burrowed mudstone. In other examples, erosional channels cut into the mound structures (McKelligon Canyon Formation of West Texas) or surround organic buildups (Kindblade Formation of Oklahoma). The resultant rock type in both instances is distinctly different from the muddy skeletal moundrock and can be classified as intraclastic skeletal packstones and grainstones composed principally of much mound-derived debris.

Last, a feature that seems to be common to all Lower Ordovician organic buildups is the almost complete lack of draping beds adjacent to the organic buildup. Only in rare cases is there any indication of very slight dips (generally less than 10 deg.) in the intermound beds as they abut against the buildup. Even the occurrence of significant amounts of mound-shed debris at this contact is an exception.

In general terms the relative simplicity of Lower Ordovician organic buildups can be explained to some extent on the stage of development of the contributing mound biota. Precursors to the Lower Ordovician organic buildups can be traced from a beginning in the Lower Cambrian with the first true organism structures, the archaeocyathid buildups. These, too, were biotically relatively simple, small-scale structures, dominated by goblet-shaped, double-walled archaeocyathids, associated, and to some extent bound and encrusted, by various *problematica* and/or algae, such as *Renalcis* (Brasier, 1976), *Epiphyton,* and stromatolites (Hill, 1972). Accessory organisms included various primitive echinoderms, simple brachiopods, trilobites, hyolithids, and other *problematica.* The organic structures formed by the archaeocyathid assemblages were vertically insignificant. Most, at maximum, only attained a height of 5 ft. with an average base diameter of approximately 36 ft. In essence, these were biostromal units that reflect intensive lateral organism clustering. This, the obvious result of organisms possessing limited constructional and binding capability. Recent work by James & Kobluk (1978) on Lower Cambrian archaeocyathid buildups of southern Labrador also emphasize the limited size and

primitive fauna and lack of diversity of these early organic structures.

By the end of Lower Cambrian time, archaeocyathid buildups had disappeared and this niche was unexploited until Lower Ordovician time. At that point in earth history, lithistid sponges allied themselves with stromatolitic algae and various *problematica* to once again take up the challenge. One interesting point that needs to be emphasized is the vast amount of elapsed time between the demise of archaeocyathid buildups in the upper Lower Cambrian, until the appearance of algal/sponge buildups in the upper Lower Ordovician. There is a total absence in the rock record of organism dominated buildups anywhere in the world during this time interval, in spite of the fact that algal-constructed buildups existed and flourished in some regions, especially in Upper Cambrian time (Ahr, 1971; Chafetz, 1973). J. L. Wilson (pers. comm.) noted that the dominantly stromatolitic algal mounds reported by Ahr (1971) from the Upper Cambrian Wilberns Formation of central Texas do contain small, rare lithistid sponges surrounding very small echinodermal growths bound by stromatolitic algae and various *problematica*, a fact Ahr did not discuss in his 1971 paper; however, he did mention (p. 211) the common presence of brachiopods and trilobites in the Wilberns algal "miniherms." Significantly, he did recognize that the various environmentally produced algal structures are found in sequences that depict a long term history of the algal buildups from their inception in subtidal waters to their culmination in the intertidal depositional regime.

## COMPARISON WITH MIDDLE ORDOVICIAN (CHAZYAN) ORGANIC BUILDUPS OF THE LAKE CHAMPLAIN REGION

The Lower Ordovician organic buildups present in West Texas and southern Oklahoma closely resemble the Middle Ordovician (Chazyan) organic buildups of northeastern New York and western Vermont in gross morphology, petrology, and basic biotic composition and sequence, although there are important temporal biotic differences when more diversified organisms occupied similar buildup niches.

These Chazyan organic buildups, which outcrop so well within the Lake Champlain region, have been the subject of a number of studies (Oxley, 1951; Erwin, 1957; Oxley & Kay, 1959; Pitcher, 1964; Fisher, 1968; Finks & Toomey, 1969; Kapp, 1975). The most detailed study is that of Pitcher (1964).

In the Lake Champlain region the Chazyan interval is subdivided into three formations: Day Point, Crown Point, and Valcour (in ascending order). The maximum thicknesses of the Day Point and Crown Point Formations are in the vicinity of Valcour Island, New York, where each formation exceeds 300 ft.; the greatest thickness of the Valcour Formation occurs on South Hero Island, Vermont, where it is approximately 200 ft. (Oxley & Kay, 1959, p. 840).

Organic buildups are present in all three Chazyan formations. Generally, the organic buildups are oval in shape with widely variable dimensions. They range in size from small domical masses 1 to 3 ft. in length and 2 ft. in height, to an average of approximately 25 ft. in height and up to 300 ft. in length. The organic buildups of the Day Point Formation are the smallest in size and the least biotically diverse, whereas the buildups of the Crown Point Formation are the largest and best developed. The dimensions and biotic diversity of the Valcour organic buildups lie somewhat between these two extremes.

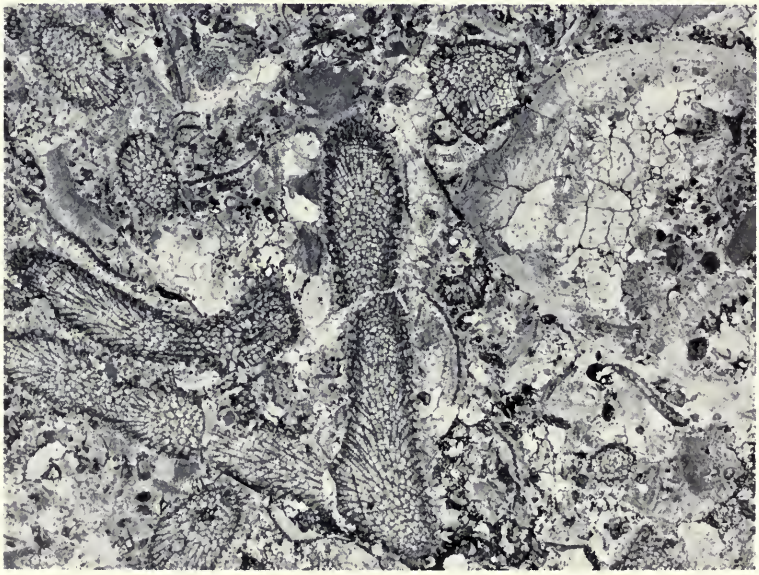
The gross morphology and relative biotic composition of the Chazyan organic buildups, particularly those of the Crown Point Formation, closely parallels that of the Lower Ordovician of West Texas and southern Oklahoma. Significantly, however, the Chazyan organic buildups are conspicuous by their more diverse and abundant biota that is temporally quite different from that of the Lower Ordovician. In fact, the beginning of Middle Ordovician (Chazyan) time marks one of the most significant periods in animal evolution. Here for the first time in earth's history a number of significant organisms, specifically, the bryozoans, stromatoporoids, and tabulate corals, either first evolved or became dominant biotic components within organic buildups. Hence, this is really the first point in geologic history in which animals with appreciable constructional capability could, and did, cluster together to form organic buildups of relatively larger size than had heretofore been possible (Wilson, 1975).

Within the Chazyan sequence the biotas of the organic buildups show a progressive increase in diversity with time. The earliest organic buildups are small structures well exposed near the base of the Day Point Formation on Garden Island in Lake Champlain (see Pitcher, 1964, fig. 10). These buildups are massive limestones less than 7 ft. in height and of undetermined length, and are composed principally of bryozoans, i.e., *Batostoma chazyenis* (Ross), *Cheiloporella* sp., and "*Phylloporina*" sp. Usually the encrusting trepostome *Batostoma* builds superimposed crescent-shaped layers binding lime mud and skeletal debris, and acting as a true boundstone. In some of the very small organic buildups, "*Phylloporina*" is the dominant bryozoan, generally in a skeletal wackestone core that contains oolites (fig. 78a). Minor amounts of quartz and feldspar silt also occur in the moundrock.

These organic buildups are surrounded by thin-bedded packstones and grainstones principally composed of well-preserved bryozoans, especially the form *Atactotoechus chazyenis* Ross (fig. 78b). Leperditid ostracodes are also conspicuous components of the surrounding non-mound rock.

In the middle of the Day Point Formation there is an accumulation of the coral, *Lichenaria heroensis,* first described by Raymond (1924). These early tabulate corals are often found fragmented and some appear to be overgrown by bryozoans. Petrologically, the coral-bearing horizon can be classified as a skeletal wackestone-packstone containing a "normal" marine biota and including

*a*



*b*

solenoporid algae and common remains of the problematical form *Nuia siberica* Maslov (Toomey, 1967). Rare oolites, and common spar-filled cavities characterize this moundrock. This coral unit is conspicuously cut by channels up to 2 ft. in diameter. The channel rock is a tightly-packed grainstone composed mainly of pelmatozoan fragments showing much calcite overgrowth. Pitcher (1964, p. 648) regards these corals as having been transported into the outcrop area. Our limited fieldwork would lead us to believe that this is an incipient *in situ* organic buildup.

In the upper Day Point Formation, above the *Lichenaria* buildup, on Isle La Motte, western Vermont, organic buildups composed almost entirely of bryozoans of the encrusting trepostome form *Bastostoma chazyenis* (Ross) are dominant (fig. 79). These are relatively small buildups, up to 6 ft. in height and 8 to 10 ft. in length and width. Of special note is the general lineation of sheet-like bryozoan colonies in these buildups, and the resultant linear organic buildup trend as shown by Pitcher (1964, fig. 19) and seen here in Figure 80a. The moundrock is a bryozoan boundstone. Significantly, a few conical lithistid sponges of the genus *Zittelella* make their first appearance in this mound interval, a foreshadow of the much richer sponge fauna of the overlying Crown Point Formation.

Contacts between the massive, light-colored moundrock and the thin-bedded, darker intermound rock is sharp, and the beds have what is believed to be primary dips away from the buildups of up to 17 deg. (fig. 80b). The intermound rock is a packstone-grainstone composed chiefly of the bryozoan *Atactotoechus* and the brachiopod *Orthambonites exfoliata* (Raymond).

Crown Point organic buildups are best developed in the middle and upper portion of the formation, especially on Isle La Motte, western Vermont. No large massive organic buildups are present in the lower part of the formation, but small stromatoporoid colonies are scattered within this interval, especially in the walls of the Goodsell Quarry, (fig. 81a).

---

*Opposite:*

FIG. 78. Thin-section photomicrographs (×4) showing mound and intermound rock of the Middle Ordovician (lower Day Point Formation) on Garden Island in Lake Champlain, New York. **(a)** Moundrock classified as a skeletal wackestone, in part oolitic; the dominant byrozoan in these small organic buildups is the form "*Phylloporina.*" **(b)** Intermound rock classified as a skeletal packstone characterized by abundant and well-preserved bryozoan colonies, especially the form *Atactotoechus chazyensis* Ross, and echinodermal fragments.

FIG. 79. Thin-section photomicrograph ( × 3) of Middle Ordovician (Chazyan), Day Point Formation moundrock from Isle La Motte, western Vermont, showing sheets of the encrusting bryozoan *Batostoma chazyensis* (Ross) with an irregular laminar growth habit. Note the abundance of entrapped mud between the bryozoan sheets.

a

b

FIG. 80. Outcrop photographs of bryozoan organic buildups exposed in the Middle Ordovician Day Point Formation on Isle La Motte in Lake Champlain, western Vermont. (a) Mound surface showing lineation of the bryozoan colonies; hammer, 15 in. long. (b) Mound surface showing sharp contact of inter-mound rock (dark-colored) with bryozoan moundrock (light-colored); the inter-mound rock is a calcarenite composed principally of bryozoan and pelmatozoan debris; hammer, 3 ft. long.

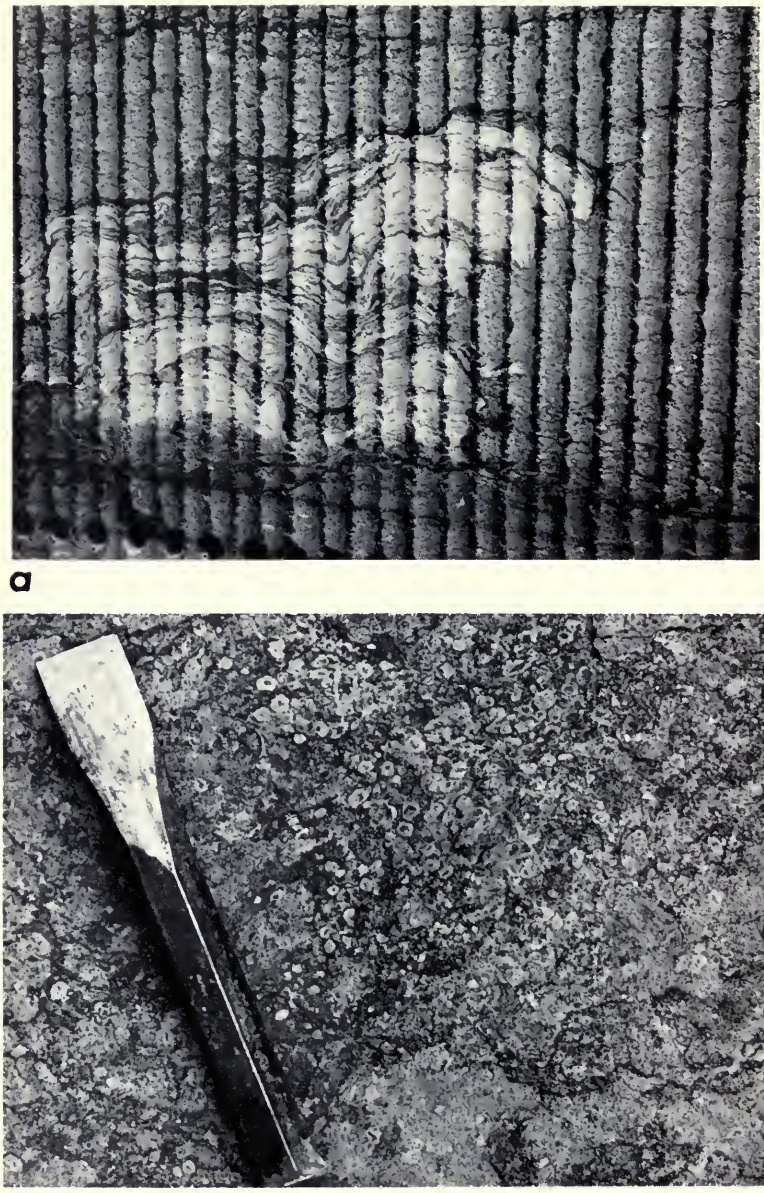
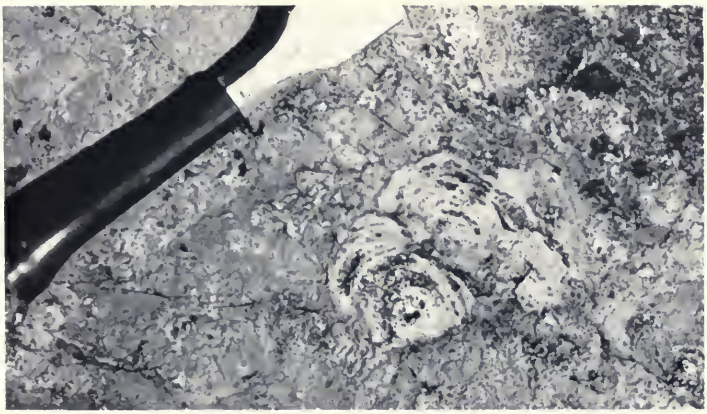


FIG. 81. **(a)** Stromatoporoid colony in the Middle Ordovician Crown Point Formation exposed on the south wall of Goodsell Quarry (6/62) on Isle La Motte, Lake Champlain, western Vermont; colony is approximately 4 ft. wide and 2½ ft. high. **(b)** Algal oncolites *(Girvanella* "pellets") exposed on a mound surface at the South Hero section, Grand Isle in Lake Champlain, western Vermont.

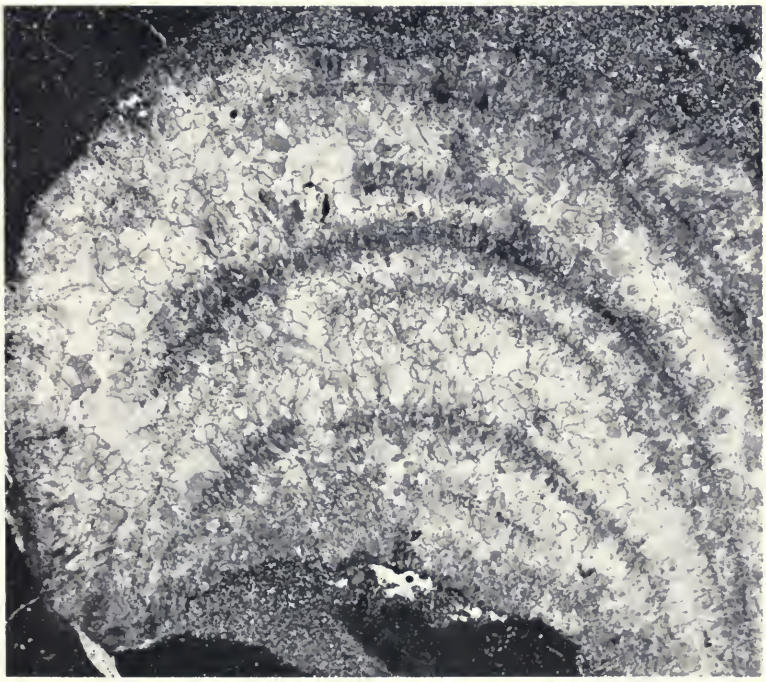
The organic buildups present in the Crown Point Formation are larger than either the Day Point or Valcour buildups. Generally, they are oval-shaped and are about 20 ft. high, 30 ft. wide, and up to 300 ft. long (see fig. 82 for a typical example). Intermound and overlying sediments are well-sorted packstones and grainstones that contain algal oncolites *(Girvanella* "pellets") (fig. 81b), recrystallized colonies, and fragments of an algal form referred to as *Solenopora*? sp. (fig. 83). The biota of the Crown Point organic buildups can be subdivided into five principal biotic component variants. The following are considered primary mound builders with distinct and variable gradations among them: (1) algæ and *problematica (Girvanella, Sphaerocodium, Solenopora*?, and *Nuia),* (2) lithistid sponges *(Zittelella, Anthaspidella,* and others), (3) tabulate corals *(Eofletcheria* and *Billingsaria),* (4) bryozoans *(Batostoma* and others), and (5) stromotoporoids *(Labechia, Pachystylostroma* (Kapp & Stearn, 1975) and *Pseudostylodictyon.* The matrix of the organic buildup is muddy, contains intraclasts, and can be classified as an intraclastic skeletal wackestone grading to a boundstone. Debris shed from the organic buildups is rarely present in the surrounding sediments, and the contacts with mound and intermound are always sharp. Sedimentary layers are only slightly arched as they drape over the organic buildup. Generally, most layers directly abut against the buildup. Individual organic buildups appear to be dominated by various organisms. In several mounds examined, the lithistid sponge *Zittelella* is the dominant organic component (fig. 84). Pitcher (1969, p. 1,349) has noted that sponges can comprise 50 per cent of the rock volume in a matrix of lime mud.

The surface distribution of organisms on a Crown Point buildup was plotted by Pitcher (1964, fig. 26) from the mound flanks to the crest. He intended to demonstrate primary bathymetric differences. In essence, he found that stromatoporoids were most abundant at the crest, bryozoans more abundant somewhat lower down, and the tabulate corals and lithistid sponges most abundant still lower on the flanks, but with sponges remaining abundant farther down than the corals. Several cores taken through Crown Point buildups seem to confirm these observations, but significantly they show that stromatoporoids are scattered biotic constituents at the base of the mounds, usually quite sparse through the middle portion, and relatively abundant on the tops. Toomey (1970, p. 1,333) suggested that the stromotoporoids of the Chazyan organic buildups occupied

FIG. 82. Outcrop photograph of a typical Middle Ordovician (Crown Point Formation) organic buildup exposed in La Bombard's Pasture, Isle La Motte, western Vermont. The shape of the mounds are due in part to glaciation. This particular elliptical-shaped organic buildup is composed of lime mud containing algae, sponges, stromatoporoids, corals, bryozoans, and pelmatozoans. The size of this structure is approximately 35 ft. long and about 12 ft. high.



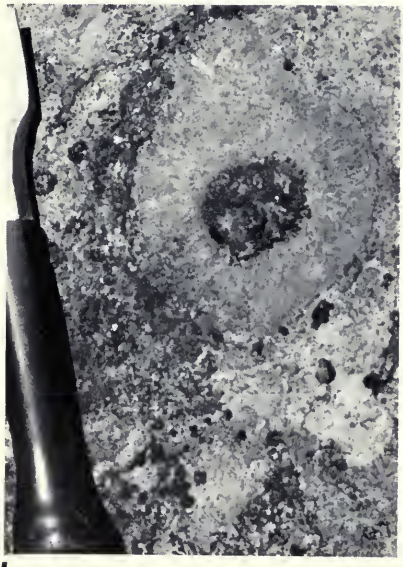
a



b

FIG. 83. Recrystallized algal remains on the surface of a middle Crown Point organic buildup, Isle La Motte in Lake Champlain, western Vermont. (a) Outcrop photograph of the mound surface showing a typical "algal" colony; chisel, 7 in. long. (b) Thin-section photomicrograph (×4) of a portion of a recrystallized colony, thought to be a red solenoporoid alga.

a



b

c

a similar ecologic niche as *Pulchrilamina* of the McKelligon Canyon Formation buildups of West Texas, that is, as the dominant elements of a climax community.

The Crown Point organic buildups are cut by numerous channels, up to 3 ft. wide and as much as 2 ft. deep. The channels are filled with a dark-colored packstone/grainstone that contrasts sharply with the more massive lighter-colored moundrock (fig. 85).

There is some evidence to suggest that these conspicuous channels may have formed subaerially by solution following consolidation of the moundrock. This sequence of events probably happened several times during Crown Point deposition because (1) the skeletal sand filling the channels contains distinctive Crown Point fossils identical to those beneath and to either side of the mound structures and (2) because such channels occur at several levels within the Crown Point beds in the same area.

On Isle La Motte the Crown Point-Valcour boundary had been delineated at a conspicuous dip slope, and by using the faunal criterion employed earlier by Oxley & Kay (1959), namely that the presence of the distinctive trilobite *Glaphurus pustulus* Raymond marks Valcour strata. However, later work has cast some doubt on the validity of this trilobite indicator, and Pitcher (1964) found that the occurrence of the bryozoan *Batostoma campensis* Ross, usually in association with the brachiopod *Rostricellula plena* Hall, were more reliable guides for delineation of Valcour strata.

The best exposures of Valcour organic buildups occur on the east side of Valcour Island, Lake Champlain, New York, where the dominant organism is the tabulate coral *Billingsarea* in association with lithistid sponges, stromatoporoids, *Batostoma*, and *Solenopora*? Indications are that lamellar stromatoporoids stabilized small areas of the substrate and provided the necessary foundation for tabulate coral dominance. At this location, there is an organic buildup in excess of 300 ft. in length and up to 10 ft. high. Another good example of this same type of organic buildup is present on Grand Isle, Ver-

*Opposite:*

FIG. 84. Sponges present in the Middle Ordovician (Chazyan) Crown Point Formation of the Lake Champlain region. (a) Thin-section photomicrograph (×4) of the lithistid sponge *Zittelella* sp. in a calcarenite from a mound channel present on Valcour Island, Lake Champlain, New York. (b) Typical appearance of the sponge *Zittelella* on a mound surface at the South Hero section, Grand Isle, western Vermont. (c) Relatively large (approximately 5 in. long) annulated sponge present on a mound near the top of the formation at the South Hero section.

FIG. 85. Outcrop photograph of a channel cutting moundrock in the Middle Ordovician (Chazyan) Crown Point Formation, west of the Goodsell Quarry, Isle La Motte, western Vermont. The width of the channel is approximately 18 in. Note lighter-colored moundrock on either side of darker-colored channel rock.

mont, in shore cliffs just north of a small bay, south of Rockwell Bay. Here, horizontal colonies of tabulate corals can be seen binding dolomitized mud, and an exceptional erosional channel cuts into the major organic buildup. This channel is 18 in. wide and almost 3 ft. deep.

In general, and especially in the Valcour outcrops on Isle La Motte, encrusting bryozoans had once again attained local predominance, specifically the form *Batostoma campensis* Ross, associated with some lithistid sponges, the tabulate coral *Eofletcheria incerta* (Billings), and stromatoporoids. Vertical differentiation with bryozoans at the base and tabulate corals toward the top, as originally described by Hofmann (1963) for Chazyan outcrops farther north, occurs only locally and is not a general sequence. Coarse grainstones containing abundant *Rostricellula plena* Hall also commonly surround Valcour buildups farther to the north in Quebec (Pitcher, 1964).

**Summary.**—Chazyan organic buildups of the Lake Champlain region are important because they show a change in biotic composition through time that reflects changing paleoenvironmental settings in a relatively limited area.

Subsequent to the initial Chazyan transgression over Lower Ordovician rocks, bryozoans constructed organic buildups in relatively shallow water. Grainstone carbonates adjacent to the buildups, cross-bedding, and quartz sand bars in equivalent beds nearby all indicate a very shallow water depositional environment for these small, early Day Point structures.

Preceding a regressive sand deposit, later Day Point cyclostome bryozoans built aligned organic buildups, probably induced by strong currents present during their growth. These too grew in shallow water and attained only very modest dimensions. The presence of cross-bedding features in sediments adjacent to the buildups, and contemporaneous oolites nearby, indicate growth and development in extremely shallow water.

By Crown Point time the organic buildup biotas had progressively evolved and various algae, lithistid sponges, stromatoporoids, and encrusting bryozoans formed the dominant mound-building components. All of these forms have representative species which could encrust and bind lime mud, and thus possessed the necessary requirements to build somewhat larger organic structures. As evidenced by packstones, grainstones, oncolites, erosional channels

cut in the organic buildups, and abundance of algae, these organic buildups must have developed in shallow subtidal waters.

Valcour organic buildups are not as well exposed or developed as those of the Crown Point. In general, they are intermediate in size and organic composition between those of the Day Point and those buildups of the Crown Point Formations. One characteristic of the Valcour buildups is that there is a return to an abundance of bryozoans, especially the encrusting *Batostoma campensis* Ross, as the dominant mound organism, and these seem to have successfully occupied the niche of the stromotoporoids within the Valcour mound assemblages.

Unfortunately, the Lake Champlain Chazyan exposures are so restricted that it has not been possible to reconstruct the regional paleogeography.

The vertical succession of Chazyan organic buildups exposed in the Lake Champlain region is outstanding because it offers us insight into the evolution of buildup organism communities, in a rather limited area, that is not seen anywhere else. The Chazyan mound assemblage is unique because it marks the very beginnings of such organism groups as stromotoporoids, and the first real abundance of the bryozoans and tabulate corals as major organic buildup components.

Since these Chazyan organic buildups grew and developed in shallow subtidal waters of a carbonate platform, and since the Chazyan buildups are the precursors of the later Silurian and Devonian organic buildups, it seems reasonable to assume that early organic buildup evolution took place on the shallow water platform. Later organic buildups are more massive and have appreciable dimensions, but most importantly, they show a vertical organic progression which suggests initial growth in deeper waters with a progression to a climax organism community in shallow waters. With the greater development of more massive corals and stromotoporoids, the organic buildups were able to migrate outward toward the deeper water at the edge of the continental shelf. This occurred because the organic buildup community evolved the necessary potential to create larger and more massive structures that could meet the obvious increasing physical demands of the environment that is coupled with a rough-water paleoenvironmental setting.

## REFERENCES


AHR, W.M.

1971. Paleoenvironment, algal structures, and fossil algae in the Upper Cambrian of central Texas. Jour. Sediment. Petrol., 41, no. 1, pp. 205-216, 8 text-figs.

ALBERSTADT, L.P. and K.R. WALKER

1975. A receptaculitid-echinoderm pioneer community in a Middle Ordovician reef. Lethaia, 9, pp. 261-272, 8 text-figs.

BAKER, C.L. and W.P. BOWMAN

1971. Geologic exploration of the southeastern front range of trans-Pecos Texas. Univ. Texas Bull. 1753, pp. 79-101.

BARNES, C.R. and M.F. TUKE

1970. Conodonts from the St. George Formation (Ordovician), northern Newfoundland. Geol. Surv. Can., Bull. 187, pp. 79-97, 3 pls.

BARNES, V.E., P.E. CLOUD, L.P. DIXON, R.L. FOLK, E.C. JONAS, A.R. PALMER, and E.J. TYNAN

1959. Stratigraphy of the pre-Simpson Paleozoic subsurface rocks of Texas and southeast New Mexico. Univ. Texas Publ. 5924, 836 pp., 65 pl., 38 text-figs., 3 vols.

BERRY, W.B.N.

1958. Depositional environment of the Ordovician succession in the Marathon region, Texas. Jour. Sediment. Petrol., 28, no. 4, pp. 389-405, 4 pls., 1 text-fig.

1960. Graptolite faunas of the Marathon region, West Texas. Univ. Texas Publ. 6005, 179 pp., 20 pls., 3 text-figs.

BILLINGS, ELKANAH

1865. Palaeozoic fossils, Vol. 1. Geol. Surv. Can., 426 pp., 401 text-figs.

BRANSON, E.B. and M.G. MEHL

1933. Conodonts from the Jefferson City (Lower Ordovician) of Missouri. Univ. Missouri Stud., 8, pp. 53-64, pl. 4.

BRASIER, M.D.

1976. Early Cambrian intergrowths of archaeocyathids, *Renalcis*, and pseudostromatolites from South Australia. Palaeontology, 19, pt. 2, pp. 223-245, pl. 35-37, 6 text-figs.

BRIDGE, JOSIAH and P.E. CLOUD, JR.

1947. New gastropods and trilobites critical in the correlation of Lower Ordovician rocks. Amer. Jour. Sci., **245**, pp. 545-559, 2 pls., 1 text-fig.

CHAFETZ, H.S.

1973. Morphological evolution of Cambrian algal mounds in response to a change in depositional environment. Jour. Sediment. Petrol., **43**, no. 2, pp. 435-446, 12 text-figs.

CHASE, G.W., E.A. FREDERICKSON, and W.E. HAM

1956. Resume of the geology of the Wichita Mountains, pp. 36-55, 1 text-fig., 2 tables. *In* Petroleum geology of southern Oklahoma, Amer. Assn. Pet. Geol., **1**.

CHURCH, S.B.

1974. Lower Ordovician patch reefs in western Utah. Brigham Young Univ. Geol. Stud., **21**, pt. 3, pp. 41-62, 3 pls., 8 text-figs.

CLOUD, P.E., JR.

1948. Brachiopods from the Lower Ordovician of Texas. Bull. Mus. Comp. Zool., **100**, no. 5, pp. 451-472, 4 pls.

CLOUD, P.E., JR. and V.E. BARNES

1946. The life and environment of the Early Ordovician sea in central Texas. Report of the Committee on Marine Ecology as Related to Paleontology, no. 6, Nat. Res. Council, pp. 87-101, 1 text-fig.

1948. The Ellenburger Group of central Texas. Univ. Texas Publ. 4621, 473 pp., 45 pls., 8 text-figs.

1957. Early Ordovician sea in central Texas. Geol. Soc. Amer., Mem. **67**, pp. 163-214, 2 text-figs.

CLOUD, P.E., JR., V.E. BARNES, and JOSIAH BRIDGE

1943. [1945] Stratigraphy of the Ellenburger Group in central Texas — a progress report. Univ. Texas Publ. 4301, pp. 133-161, pls. 7-8.

COOPER, G.A.

1952. New and unusual species of brachiopods from the Arbuckle Group in Oklahoma. Smithsonian Misc. Coll., **117**, no. 14, 35 pp., 4 pls.

DAKE, C.L. and JOSIAH BRIDGE

1932. Faunal correlation of the Ellenburger limestone of Texas. Geol. Soc. Amer., Bull., **43**, no. 9, pp. 725-748, pl. 12, 2 text-figs.

DECKER, C.E.

1939. Progress report on the classification of the Timbered Hills and Arbuckle Groups of rocks, Arbuckle and Wichita Mountains, Oklahoma. Okla. Geol. Surv. Circ. 22, 62 pp., 5 pls., 1 table.

DUNHAM, R.J.

1962. Classification of carbonate rocks according to depositional texture, pp. 108-121, 7 pls., 1 table. *In* Ham, W.E., ed., Classification of carbonate rocks, a symposium. Amer. Assn. Pet. Geol. Mem. 1.

ERWIN, R.B.

1957. The geology of the limestone of Isle La Motte and South Hero Island, Vermount. Vt. Geol. Surv., Bull., **9**, 94 pp., 20 pls., 3 tables.

ETHINGTON, R.L. and D.L. CLARK

1964. Conodonts from the El Paso Formation (Ordovician) of Texas and Arizona. Jour. Paleontol., **38**, no. 4, pp. 685-704, pls. 113-115, 2 text-figs.

1965. Lower Ordovician conodonts and other microfossils from the Columbia Ice Fields Section, Alberta, Canada. Brigham Young Univ. Geol. Stud., **12**, pp. 185-205, 2 pls.

1971. Lower Ordovician conodonts in North America. Geol. Soc. Amer., Mem. 127, pp. 63-82, 2 pls., 2 text-figs.

FIELD, R.M.

1931. Geology of the Bahamas. Geol. Soc. Amer. Bull., **42**, pp. 759-784, pls. 18-21, 6 text-figs.

FINKS, R.M. and D.F. TOOMEY

1969. The paleoecology of Chazyan (lower Middle Ordovician) "reefs" or "mounds." N.Y. State Geol. Assn., Guidebook 41st. Ann. Mtg., Plattsburgh, pp. 93-120, 6 pls., 4 text-figs.

FISHER, D.W.

1968. Geology of the Plattsburgh and Rouses Point, New York-Vermont quadrangles. N.Y. State Mus. Sci. Service, Map Chart Ser. No. 10, 51 pp., 2 pl., 37 text-figs, 1 table.

FLAWN, P.T.

1969. The regional setting of the Marathon salient, pp. 23-28, 1 text-fig. *In* McBride, E.F., ed., A guidebook to the stratigraphy, sedimentary structures and origin of flysch and pre-flysch rock of the Marathon Basin, Texas, Dallas Geol. Soc.

FLOWER, R.H.

1957. Studies of the Actinoceratida. N.M. Bur. Mines Miner. Resour., Mem. 2, 101 pp.

1964. The nautiloid order Ellesmeroceratida (Cephalopoda). N.M. Bur. Mines Miner. Resour., Mem. 12, 234 pp., 32 pls., 53 text-figs.

FURNISH, W.M.

1938. Conodonts from the Prarie du Chien beds of the upper Mississippi Valley. Jour. Paleontol., **12**, no. 4, pp. 318-340, pls. 41-42, 2 text-figs.

GRAVES, R.W., JR. and S. ELLISON

1941. Ordovician conodonts of the Marathon Basin, Texas. Mo. Univ. Sch. Mines Metall. Bull., Tech. Ser., **14**, no. 2, 26 pp., 3 pls., 2 text-figs.

HAM, W.E.

1951. Structural geology of the southern Arbuckle Mountains. Tulsa Geol. Soc. Dig., **19**, pp. 68-71.

1955. Field conference on the geology of the Arbuckle Mountain region. Okla. Geol. Surv., Guidebook-3, 61 pp., 21 text-figs., 2 tables, 1 map.

HAM, W.E. and E.A. FREDERICKSON

1947. Cambrian and Ordovician rocks of the Wichita Mountains. N. Texas Geol. Soc. Fieldtrip Guideb., 10 pp., 2 text-figs., 1 map.

HAM, W.E., E.A. FREDERICKSON, and G.B. CHASE

1949. Precambrian, Cambrian and Ordovician rocks of the Wichita Mountains area. Okla. City Geol. Soc. Fieldtrip Guideb., 17 pp., 2 text-figs., 1 map.

HAM, W.E., C.A. MERRITT, and E.A. FREDERICKSON

1957. Field conference on the geology of the Wichita Mountains region. Okla. Geol. Surv. Guidebook-5, 58 pp., 14 text-figs., 1 map, 1 table.

HAM, W.E., R.E. DENISON, and C.A. MERRITT

1964. Basement rocks and structural evolution of southern Oklahoma. Okla. Geol. Surv. Bull. 95, 302 pp., 16 pls., 19 text-figs., 18 tables.

HAM, W.E. and D.F. TOOMEY

1966. Carbonate mounds in the Lower Ordovician of West Texas and southern Oklahoma (abstr.) Geol. Soc. Amer., Program Ann. Mtg., San Francisco, pp. 83-84.

HAM, W.E. and J.L. WILSON

1967. Paleozoic epeirogeny and orogeny in the central United States. Amer. Jour. Sci., 265, pp. 332-407, 12 text-figs., 1 table.

HAM, W.E., J.H. STITT, J.R. DERBY, R.O. FAY, and A.A. GRAFFHAM

1968. Regional geology of the Arbuckle Mountains. Fieldtrip guidebook 53rd. Ann. Mtg. Amer. Assn. Pet. Geol., Oklahoma City, 61 pp., 1 pl., 23 text-figs., 1 table.

HAYES, P.T.

1975. Cambrian and Ordovician rocks of southern Arizona and New Mexico and westernmost Texas. U.S. Geol. Surv. Prof. Paper 873, 98 pp., 1 pl., 51 text-figs., 1 table.

HILL, DOROTHY

1972. Treatise on Invertebrate Paleontology, Pt. E, Archaeocyatha. Geol. Soc. Amer. and Univ. Kansas, 158 pp., 107 text-figs.

HILL, R.T.

1900. Physical geography of the Texas region. U.S. Geol. Surv. Topographic Atlas Folio 3.

HINTZE, LEHI

1951. Lower Ordovician detailed stratigraphic section for western Utah. Utah Geol. Miner. Surv. Bull. 39, 99 pp.

1952. Lower Ordovician trilobites from western Utah and eastern Nevada. Utah Geol. Miner. Surv. Bull. 48, 249 pp.

HOFMANN, H.J.

1963. Ordovician Chazyan Group in southern Quebec. Bull. Amer. Assn. Pet. Geol., 47, no. 2, pp. 270-301, 13 text-figs., 2 tables.

1975. Stratiform Precambrian stromatolites, Belcher Islands, Canada: relations between silicified microfossils and microstructure. Amer. Jour. Sci., **275**, pp. 1,121-1,132, 4 pls., 1 text-fig.

JAMES, N.P. and D.R. KOBLUK

1978. Lower Cambrian patch reefs and associated sediments: southern Labrador, Canada. Sedimentology, **25**, no. 1, pp. 1-35, 12 text-figs.

KAPP, U.S.

1975. Paleoecology of Middle Ordovician stromotoporoid mounds in Vermont. Lethaia, **8**, pp. 195-207, 9 text-figs.

KAPP, U.S. and C.W. STEARN

1975. Stromotoporoids of the Chazy Group (Middle Ordovician), Lake Champlain, Vermont and New York. Jour. Paleontol., **49**, no. 1, pp. 163-186, 6 pls., 4 text-figs.

KELLEY, V.C. and CASWELL SILVER

1952. Geology of the Caballo Mountains. Univ. N.M. Publ. Geol. No. 4, 286 pp., 19 pls., 26 text-figs.

KING, P.B.

1931. Pre-Carboniferous stratigraphy of the Marathon Uplift, West Texas. Bull., Amer. Assn. Pet. Geol., **15**, no. 9, pp. 1,059-1,085, 4 text-figs.

1937. Geology of the Marathon region, Texas. U.S. Geol. Surv. Prof. Paper 187, 148 pp., 24 pls., 33 text-figs.

KIRK, EDWIN

1934. The Lower Ordovician El Paso limestone of Texas and its correlatives. Amer. Jour. Sci., **28**, ser., 5, pp. 443-463.

KLEMENT, K.W. and D.F. TOOMEY

1967. Role of the blue-green alga *Girvanella* in skeletal grain destruction and lime-mud formation in the Lower Ordovician of West Texas. Jour. Sed. Pet., **37**, no. 4, pp. 1,045-1,051, 7 text-figs.

KOTTLOWSKI, F.E.

1963. Paleozoic and Mesozoic strata of southwestern and southcentral New Mexico. N.M. Bur. Mines Miner. Resour. Bull. 79, 100 pp., 18 text-figs., 2 tables.

KOTTLOWSKI, F.E., D.V. LEMONE and R.W. FOSTER

1969. Early Ordovician highlands of Precambrian rocks and their associated facies, pp. 134-151, 5 text-figs. *In* LeMone, D.V., ed., Ordovician symposium, El Paso Geol. Soc. and Permian Basin S.E.P.M.

LEMONE, D.V.

1967. Early Ordovician highlands of Precambrian rocks and their associated facies, Franklin Mountains, Texas (Abs.). Geol. Soc. Amer., Spec. Paper 115, pp. 129-130.

1969a. Cambrian-Ordovician in the El Paso border region, pp. 145-162. *In* Ordovician symposium, El Paso Geol. Soc., 3rd Ann. Fieldtrip.

1969b. Cambrian-Ordovician in El Paso border region, pp. 17-25, 1 table. *In* Kottlowski, F.E. and D.V. LeMone, eds., Border stratigraphy symposium, N.M. Bur. Mines Miner. Resour., Circ. 104.

LUCIA, F.J.

1969. Sedimentation and paleogeography of the El Paso Group, pp. 110-133, 12 text-figs. *In* LeMone, D.V., ed., Ordovician symposium. El Paso Geol. Soc. and Permian Basin S.E.P.M.

MIAGKOVA, E.I.

1965. Soanity-novaja gruppa organizmov. Paleontol. Zh., no. 3, pp. 16-22, 2 pls., 3 text-figs.

1973. K ekologii ranneordovikckih soanitov, pp. 65-69, 3 figs. *In* Sreda i Schizn b. Geologicheskom Proshlom. Nauka. Novosibirsk.

MOSKALENKO, T.A.

1967. Conodonts from the Chunsky Stage (Lower Ordovician) of the rivers Moiero and Podkamennay Tunguska, pp. 98-116, 4 pls. *In* Ivanovskii, A.B. and Sokolov, B.S., eds., New data on the biostratigraphy of the Lower Paleozoic deposits of the Siberian Platform. Akad. Nauk S.S.S.R., Sib. Otdel., Inst. Geol. Geofiz.

NITECKI, M.H.

1969. Algal nature of calathids. 11th Intn. Bot. Congr. Abstr. p. 159.

OXLEY, PHILIP

1951. Chazyan reef facies relationships in the northern Champlain Valley. Bull. Denison Univ., Jour. Sci. Lab., 42, pp. 92-111, 5 pls., 2 text-figs.

OXLEY, PHILIP and MARSHALL KAY

1959. Ordovician Chazyan Series of Champlain Valley, New York and Vermont and its reefs. Bull. Amer. Assn. Petrol. Geol., 43, no. 4, pp. 817-853, 10 text-figs.

PAIGE, SIDNEY

1911. Mineral resources of the Llano-Burnet region, Texas. U.S. Geol. Surv. Bull. 450, 103 pp., 5 pls., 22 text-figs.

1912. Llano-Burnet Folio. Geol. Atlas No. 183, U.S. Geol. Surv. 16 pp., 11 pls., 6 text-figs, map.

PITCHER, MAX

1964. Evolution of Chazyan (Ordovician) reefs of eastern United States and Canada. Bull. Can. Petrol. Geol., 12, no. 3, pp. 632-691, 3 pls., 49 text-figs.

1969. Middle Ordovician reef assemblages. Proc. N. Amer. Paleontol. Conv., pt. J. pp. 1,341-1,357, 16 text-figs.

RAYMOND, P.E.

1924. The oldest coral reef. Rept. Vt. State Geol., no. 14, pp. 72-76, 1 pl., 1 text-fig.

RICHARDSON, G.B.

1904. Report of a reconnaissance in the trans-Pecos Texas, north of the Texas & Pacific Railroad. Texas Univ. Publ. 23 (Min. Survey Bull. 9), 119 pp., 11 pl., 4 text-figs.

1908. Paleozoic formations in trans-Pecos Texas. Amer. Jour. Sci., **25**, ser. 4, pp. 474-484, 1 text-fig., 1 table.

RIDING, ROBERT and D.F. TOOMEY

1972. The sedimentological role of *Epiphyton* and *Renalcis* in Lower Ordovician mounds, southern Oklahoma. Jour. Paleontol., **46**, no. 4, pp. 509-519, 2 pl., 3 text-figs., 1 table.

RIDING, ROBERT and MARTIN BRASIER

1975. Earliest calcareous Foraminifera. Nature, **257**, pp. 208-210, 1 text-fig., 1 table.

RIGBY, J.K.

1965. Stratigraphy and Porifera of Ordovician rocks near Columbia icefields, Jasper National Park, Alberta, Canada. Brigham Young Univ. Geol. Stud., **12**, pp. 165-184, 6 pls., 2 text-figs.

1966. Evolution of Lower and Middle Ordovician sponge reefs in western Utah (Abs.). Geol. Soc. Amer., Spec. Papers no. 87, p. 137.

1971. Sponges and reef and related facies through time. Proc. N. Amer. Paleontol. Conven., part J, pp. 1,374-1,388, 9 text-figs.

RIGBY, J.K. and D.F. TOOMEY

1978. A distinctive sponge spicule assemblage from organic buildups in the Lower Ordovician of southern Oklahoma. Jour. Paleontol., **52**, no. 2, pp. 501-506, 3 text-figs.

ROBERTS, H.H.

1967. Survey of reef-like structures in the Pogonip Group (Ordovician) of southwestern Utah (Abstr.). Geol. Soc. Amer. Mtg., Golden, Colo., p. 442.

ROSS, J.P.

1964. Morphology and phylogeny of early Ectoprocta. Geol. Soc. Amer., Bull., **75**, pp. 927-948, 10 text-figs., 2 tables.

1966. Early Ordovician ectoproct from Oklahoma. Okla. Geol. Notes, **26**, no. 8, pp. 218-224, 3 pls.

ROSS, R.J., JR.

1951. Stratigraphy of the Garden City Formation in northeastern Utah and its trilobite faunas. Yale Univ., Peabody Mus. Nat. Hist., Bull. 6, 161 pp.

1972. Fossils from the Ordovician bioherm at Meiklejohn Peak, Nevada. U.S. Geol. Surv. Prof. Paper 685, 47 pp., 18 pls., 13 figs.

SERPAGLI, ENRICO

1974. Lower Ordovician conodonts from Precordilleran Argentina (Province of San Juan). Soc. Paleontol. Ital., Boll., **13**, pp. 17-93, pls. 7-31.

SMITH, A.G. and D.F. TOOMEY

1964. Chitons from the Kindblade Formation. Okla. Geol. Surv., Circ. 66, 41 pp., 8 pls., 2 text-figs.

SMITH, C.L.

1940. The Great Bahama Bank, I. General hydrographic and chemical factors:

II. Calcium carbonate precipitation. Yale Univ., Bingham Oceanographic Lab., Sears Found. Marine Res., 3, no. 2, pp. 147-189, text-figs. 44-52.

STEVENS, R.K. and N.P. JAMES

1976. Large sponge-like reef mounds from the Lower Ordovician of West Newfoundland (Abstr.). Geol. Soc. Amer., Abstr. Progr. Denver Mtg., p. 1,122.

TAFF, J.A.

1928. Preliminary report on the geology of the Arbuckle and Wichita Mountains in Indian Territory and Oklahoma. Okla. Geol. Surv. Bull. 12, 95 pp., 8 pls., 1 text-fig.

THOMSON, ALAN and E.F. MCBRIDE

1964. Summary of the geologic history of the Marathon Geosyncline, pp. 52-60, 2 text-figs. *In* Guide and symposium: The filling of the Marathon Geosyncline. Permian Basin Section S.E.P.M. Publ. 64-9.

TOOMEY, D.F.

1964. Ellenburger (Lower Ordovician) sponge beds of central Texas. Tulsa Geol. Soc. Dig., 32, pp. 98-111, 3 pls., 2 text-figs.

1967. Additional occurrences and extension of stratigraphic range of the problematical micro-organism *Nuia*. Jour. Paleontol., 41, no. 6, pp. 1,457-1,460, pl. 185.

1970. An unhurried look at a Lower Ordovician mound horizon, southern Franklin Mountains, West Texas. Jour. Sediment. Pet., 40, no. 4, pp. 1,318-1,334, 15 text-figs., 2 tables.

TOOMEY, D.F. and K.W. KLEMENT

1966. A problematical micro-organism from the El paso Group (Lower Ordovocian) of West Texas. Jour. Paleontol., 40, no. 6, pp. 1,304-1,311, pls. 159-160, 1 text fig.

TOOMEY, D.F. and W.E. HAM

1967. *Pulchrilamina*, a new mound-building organism from Lower Ordovician rocks of West Texas and southern Oklahoma. Jour. Paleontol., 41, no. 4, pp. 981-987, pls. 127-128, 2 text-figs.

TOOMEY, D.F. and R.M. FINKS

1969. Middle Ordovician (Chazyan) mounds, southern Quebec, Canada: a summary report. N.Y. State Geol. Assn., Guidebook 41st. Ann. Mtg., Plattsburgh, pp. 121-134, 5 text-figs., 2 tables.

TWENHOFEL, W.H. ed.

1954. Correlation of the Ordovician formations of North America. Geol. Soc. Amer., Bull., 56, no. 3, pp. 247-298, chart.

UDDEN, J.A.

1907. Sketch of the geology of the Chisos country. Univ. Texas Bull. 93, pp. 18-20.

ULRICH, E.O. and G.A. COOPER

1938. Ozarkian and Canadian Brachiopoda. Geol. Soc. Amer., Spec. Papers No. 13, 323 pp., 58 pls., 14 text-figs.

UNKLESBAY, A.G.

1961. Nautiloids from the Gorman and Honeycut of central Texas. Jour. Paleontol., 35, no. 2, pp. 373-379, pls. 51-52, 1 text-fig.

WILSON, J.L.

1954. Ordovician stratigraphy in Marathon folded belt, West Texas. Bull., Amer. Assn. Pet. Geol., 38, no. 12, pp. 2,455-2,475, 3 text-figs.

1975. Carbonate facies in geologic history. Springer-Verlag, Berlin-Heidelberg-New York. 471 pp.

YOCHELSON, E.L.

1973. The late Early Ordovician gastropod *Ceratopea* in the Arbuckle Mountains, Oklahoma. Okla. Geol. Notes, 33, no. 2, pp. 67-78, 4 text-figs.

1975. Early Ordovician gastropod opercula and epicontinental seas. Jour. Res. U.S. Geol. Surv., 3, no. 4, pp. 447-450.

YOCHELSON, E.L. and JOSIAH BRIDGE

1957. The Lower Ordovician gastropod *Ceratopea*. U.S. Geol. Surv. Prof. Paper 294-H, pp. 281-304, pls. 35-38, text-figs. 102-104, 3 tables.

YOUNG, L.M.

1969. Stratigraphy and sedimentology of the Marathon Formation, pp. 32-42, 6 text-figs. *In* McBride, E.F., ed., A guidebook to the stratigraphy, sedimentary structures and origin of flysch and pre-flysch rocks of the Marathon Basin, Texas. Dallas Geol. Soc.

1970. Early Ordovician sedimentary history of Marathon Geosyncline, trans-Pecos Texas. Bull. Amer. Assn. Pet. Geol., 54, no. 12, pp. 2,303-2,316, 12 text-figs.

Publication 1299

UNIVERSITY OF ILLINOIS-URBANA
550.5FIN.S. C001
FIELDIANA, GEOLOGY NEW SERIES CHGO
1-6 1979-81
3 0112 026616190